MORPHOLOGICAL STUDIES OF THE EFFECTS OF GAMMA-RAYS ON LINUM USITATISSIMUM L. VAR. NEELUM

ABSTRACT

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DOCTOR OF PHILOSOPHY
IN
BOTANY

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ALIGARH
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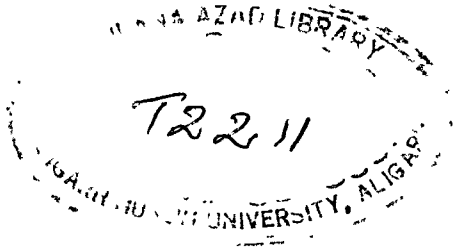

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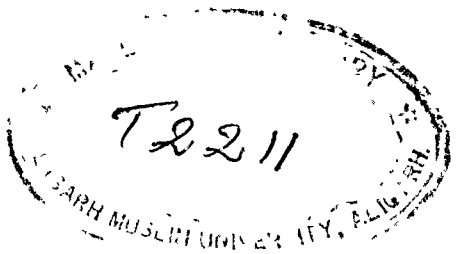
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ABSTRACT

The effect of gamma-irradiation in Linum usitatissimum L. var. neelum has been studied in relation to morphological, anatomical and various growth responses of the crop under field conditions. The gamma-ray treatments involving intensities of 25 to 150 krads have been given to the seeds at dry condition. The treated seeds were sown in completely randomized one square meter microplots at the rate of 100 seeds per plot with five replicates. The results obtained in the present study are summarised below:

1. The gamma-ray treatment does not appear to effect seed germination in the selected variety of Linum materially except at higher dose levels of 125 and 150 krads in which the process is getting delayed and hampered. In contrary to the past observations in certain crop plants, in the present study no stimulatory effect of gamma-rays at any level of dosage has been observed. The damaging effect of gamma-rays has not been observed in the second progeny of the treatments.

2. The survival fitness of the treated progenies has been found to be highly affected by the gamma-ray treatments in a direct proportion to the level of dosage. The M_2 plants of the corresponding treatments have, however, been found to recover almost to its full extent.

3. The gamma-ray treatments have been observed to affect the different growth characteristics of the crop in a linear proportion to the dosage level.

4. The length of hypocotyl region of the seedlings has been found to undergo reduction under gamma-ray treatments. The M_2 progenies have been found to recover from this loss and they are stimulated to some extent by the low level doses.

5. The cotyledonary expansion as well as the dry matter content does not appear to undergo any marked alteration due to gamma-irradiation in M_1 as well as M_2 generations, although the fresh weight/dry weight ratio goes slightly higher in the first generation indicating the water holding capacity of the cotyledons of the treated progenies.

6. A general suppression in the root growth has been caused by gamma-ray treatments. The high doses above 75 krad have been found to retard root growth to a considerable extent. At no stage any stimulatory effect on roots has been noted in the M_1 generation. A general recovery from the bad effect of irradiation has been found to occur in the M_2 generation.

7. The height of the plant is highly affected by the gamma-ray treatment, the retardation in the rate of growth of

the shoot-axis is being high at higher level of doses. The light doses, at the same time, have been found to stimulate the shoot growth. In M_2 generation the stimulatory effect of low doses has been found to persist while under high doses, the progenies recover to a considerable extent.

8. The gamma-ray treatments have been found to stimulate branching habit of the plant under low levels of irradiation while the same has been found to get affected under high levels of irradiation. No such effect of the treatments has been noticed in the M_2 generation.

9. The number of leaves/plant has been found to be influenced by the gamma-ray treatments. While a low dosage like 25 krad has been found to bring about a slight increase in the number of leaves per plant, the other doses have brought down the leaf number, and the loss being directly proportional to the intensity of dosage. The gamma-ray effect has been found not to lost in the second generation.

10. The upper-ground, under-ground and the total biomass of the treated progenies have been found to be affected materially by gamma-irradiation treatments in a direct proportion to the dose level. This adverse effect on biomass of the gamma-rays does not repeat in the second generation. M_2 generation appears to undergo considerable

recovery of the losses incurred in the first generation due to irradiation, indicating the change in the biomass production of the progenies to be a mere growth disturbance rather than a permanent genetical change.

11. The gamma-ray treatments given to the seeds have been found to reduce the yield of the progenies by affecting the number of capsules/plant and the number of seeds/capsule in a direct proportion to the dose level. In M_2 generation, an increase in yield in terms of number of fruit per plant has been observed under low doses like 25 and 50 krads. No change in yield in 75 krad and a reduced one in higher dose have been found in the second generation, the reduction being considerably low in this generation in comparison to that of first.

12. The yield in terms of oil content has been found to be effected by the gamma- ray treatments but not in a direct relation to the dose level. In M_2 generation, the lose in oil content of the seeds appear to undergo recovery and at the same time an enhancement at the lowest as well as at the highest levels of irradiation treatments indicating the effect being inconsistent and irregular.

13. The relative amounts of various fatty acid components have been found to undergo a change in the ratio of the

saturated and unsaturated components under the influence of irradiation treatments. The disturbance in the above ratio has also been observed to exist in the second generation.

a - Linolenic acid content of the oil has been found to increase in the treated progenies except under 150 krad treatment in M_1 generation and there has been an over all increase in this fatty acid content of the oil in second generation under all levels of irradiation including the 150 krad treatment.

b - Linoleic acid content of the oil has been found to increase in all the treated progenies of M_1 generation excepting the 150 krad treatment but in the second generation an increase in this fatty acid content has met with only upto 100 krad treatment, while under the other two treatments (125 and 150 krads) its amount has been found to fall below the line of control.

c - Oleic acid content has been found to decrease in all the treated progenies except that of 150 krad treatment in which its amount raises above the level of control. In M_2 generation, however, there is a consistent decrease of the Oleic acid fraction irrespective of the dose level.

d - Stearic acid component of the oil increases in the progenies of 25 and 50 krad treatments but not in other treatments of M_1 generation. In the second generation, an increase in Stearic acid component has been found under all treatments except that of 100 and 150 krads.

e - There is a general decreasing trend of the Palmatic acid content under all treatments excepting that of 75 krad in which a reverse trend has been noted. In M_2 generation, this fatty acid component has been found to decrease under all treatments with out any exception.

14. A number of morphological and anatomical variations have been found to occur in the gamma-ray treated progenies. The frequency of variance has been found to increase with the increasing dosage of gamma-irradiation. The following variations have been come across in the different treated progenies.

a - Stem bifurcation, twisting, fasciation, variegation and converaion of shoot-apex into leaf-like structure.

b - Reduction, fusion, deformation, variegation and curling of leaves.

c - Flattening and condensation of floral axis and reduction, discolouration and fusion of flowers.

d - Reduction in the length of vessels and fibres.

No variation of the above kind has been noted in the M_2 generation except the dimensional one of the secondary xylem components and this too has been noted to undergo a considerable amount of recovery in M_2 generation.

DEDICATED TO MY RESPECTED

TEACHERS

AND

PARENTS

CERTIFICATE

I place on record that the thesis entitled "Morphological studies of the effects of gamma-rays on *Linum usitatissimum* L. var. neelum" submitted for the award of the Degree of Doctor of Philosophy (Botany) to the Faculty of Science, Aligarh Muslim University, Aligarh, is a faithful record of the bonafide research work carried out by Mr. Syed Hasan Abidi under my guidance and supervision.

No part of the thesis has been submitted or utilized for any other Degree or Diploma.

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aligarh.

A C K N O W L E D G E M E N T S

All praise be to ALLAH who gave the guidance and blessings to get the strength to do this humble work.

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C O N T E N T S

INTRODUCTION

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Plant development represents a regular pattern of growth and differentiation processes including numerous correlative phenomena. Exposure of green plants to various chemical and physical mutagens may upset this balance and induce cytological, morphological and physiological changes in the cells which are usually reflected as morphogenetic abnormalities. The ability of ionizing radiations to speed up the frequency of teratological changes has been greatly exploited in understanding various fundamental problems of life processes and in improving crops through mutation in recent years. Radiation, therefore, may be considered as a valuable tool for developmental analysis, particularly where many events in growth are not observed because of a time factor.

A considerable amount of literature is presently available on the effects of ionizing radiations on plants (Johnson, 1936c; Gunckel and Sparrow, 1954, 1961; Sparrow and Gunckel, 1956; Gordon, 1957; Saeq and Alexander, 1961; Sparrow et al., 1971). As pointed out by Gunckel (1957, 1965), the response elicited depends upon the species, its age, physiological conditions, radiosensitivity, dose rate and various environmental conditions. Gunckel (1957) has emphatically suggested that the result from one species or variety should not be

applied to others as different types of responses are to be expected in different plants or even at different stages of development in the same plant.

The radiation work on cultivated plants has largely been confined to barley, wheat, mustard, castor, broad bean and peas, whereas one important field crop which has not yet received as much investigative attention as it deserves is Linum usitatissimum L. (Linseed).

The importance of Linum usitatissimum L. as a crop plant, has been realized from very remote times, as a source of manufacture of linen as well as linseed oil. It has been cultivated so long that it is not now known in its wild state, although an annual form grows as an escape in the vicinity of the Persian Gulf and the Caspian and Black Seas. The first cultivated form was a biennial type, with small, narrow leaves, Linum angustifolium Hude.; but the annual or common flax, L. usitatissimum, has been grown in Mesopotamia for at least 4000 years. The common flax, L. usitatissimum belongs to the family Linaceae which has 12 genera and 290 species of wide geographical distribution. The family is distinguished by pentamerous flowers, with contorted corolla composed of distinct and usually clawed fugacious petals and by shortly connate filaments and septicidally dehiscent capsule.

L. usitatissimum is the only species of commercial importance, in addition to a few, which are grown for decorative purposes.

Two distinct types of flax have been developed: those known as fibre flax, which produce fibre for linen, and those known as seed-flax, which produce oilseeds for linseed oil. The seed crop does well under moderate cold but the fibre crop grows best in cool moist climates.

The major portion of the crop is produced in Russia, but the fibre of the finest quality is grown in Belgium and Holland. Other countries which raise flax commercially include Austria, Hungary, France, Ireland and to a lesser degree Germany, Italy, Rumania and Japan. In Argentina, India and the United States, the crop is grown chiefly for the linseed oil, rather than for the fibre, and is known as seed-flax.

Linseed is grown in the range of latitudes between 10th and 65th parallels both north and south. Areas with annual precipitations from 45 to 75 centimeters are suited for its cultivation. The crop is cultivated throughout the plains of India upto an altitude of 1,800 m. The seeds are sown in the month of October and November (rabi season) and the crop matures by the end of March or April, depending upon the time of sowing and variety grown. Three species are recorded in India of which Linum usitatissimum L. is cultivated widely for its oil-seed. L. bienne Mill. Syn. L. angustifolium Huds. and L. grandiflorum Desf. are grown in gardens as ornamentals. The diploid chromosome number of Indian types is 30.

Linseed can be grown on different kinds of soil except the sandy drained heavy clays but does best on clay-loams. It does well on the deep clayey black soils of central and Peninsular India and the alluvium loams of the Indo-Gangetic plains.

India accounts for an area of about 4.3 million acres and a production of 3.9 lakh tonnes and occupies the fifth rank among the linseed producing countries of the world. Among the various states of India, Madhya Pradesh leads in acreage followed by Uttar Pradesh and Maharashtra.

Types grown for fibre are generally slender tall-growing, non-tillering and sparingly branched. Those grown for seed are usually dwarf in habit, much branched and profusely tillering. Linseed is cultivated in India entirely for the seeds. Two ecological types may be distinguished: (i) Gangetic types of the alluvial soils of North India and (ii) Peninsular types grown south of Ganges and Jamuna.

Gangetic types possess shallow tap-roots while Peninsular types have roots which penetrate deep into the soil and develop secondary roots. The latter are generally quick growing and early maturing, while alluvial types are slow-growing and late maturing. Seeds of Peninsular types are large and rich in oil, but the yield of seed is low; those of alluvial types are small, poor in oil, but give high yields of seeds.

The oil content of the seed varies from 33 to 47% in different varieties. Linseed oil is an excellent drying oil which is extensively used in the preparation of paints, varnishes, printing inks, oil-cloth and water-proof fabrics, and as edible oil in some areas. The residual cake is a valuable cattle feed as well as manure. The stalks are used for fuel, but sometimes coarse fibre is extracted from them.

The earliest work on radiation effects on Linum species was reported by Johnson (1936c). Sparrow and Gunckel (1956) observed severe radiation damage and D'Amato (1957) noticed a very high incidence of fasciation in flax plants exposed to chronic gamma-irradiation. The effects of acute irradiation on seeds of flax have also been reported by other workers (Gustafsson, 1944; Levan, 1944). Recently Bari (1971) studied the effects of chronic and acute irradiation on morphological characters and seed yield in flax. Though a good deal of information is available on responses to ionizing radiations given acutely or chronically, yet our knowledge regarding their effects on various aspects of growth and development including floral morphology and anatomy, is extremely meagre in flax and particularly on the Indian varieties. Similarly, informations regarding the oil content and fatty acid composition with reference to irradiation on this species are scanty and provide scope for further studies.

The present work deals with germination, survival, general growth pattern, anatomy, floral morphology, oil content and fatty acid composition of Linum usitatissimum L. var. neelum with reference to different acute doses of gamma-rays in two consequent generations.

MATERIAL AND METHODS

MATERIAL AND METHODS

The seeds of var. neelum of Linum usitatissimum L. used in the present investigation were obtained from Economic Botanist, Oil Seeds' Section of Chandra Shekhar Azad Agriculture University, Kanpur (India). They were tested for their viability with tetrazolium chloride and exposed to six different acute doses of gamma-rays (25, 50, 75, 100, 125 and 150 krads) having ^{60}Co as a source in the gamma-chamber of Radiation Biology Laboratory, National Botanic Research Institute, Lucknow (India). Twelve hundred seeds were irradiated per treatment after packing and sealing in small polythene bags along with slips having details of the samples. The irradiated material was brought to Aligarh and the sowing was done on the second day along with the untreated seeds which served as control, at the experimental station (Fort) of Botany Department, Aligarh Muslim University, Aligarh. The experimental field was irrigated, ploughed, manured and replaughed before it was converted into seventy small microplots of 1 sq. m. size. Other Agricultural and cultural practices recommended for this crop were also followed. The microplots were prepared two days earlier to sowing and the beds retained sufficient moisture at the time of sowing. Sowing was done in the first week of November, 1977 for raising plants of M_1 generation and the seeds obtained from M_1 population were sown in the first week of November, 1978 to raise M_2 plants.

The seed germination and plant survival studies in pot conditions were also carried out by sowing the treated and untreated seeds in earthen pots (22 centimeter in diameter) containing a mixture of garden soil and manure (compost) in a ratio of 4:1. In each treatment, hundred seeds were sown at the rate of twenty seeds per pot. There were five replications in each of the seven treatments. Precaution was taken to sow the seeds at uniform depth and distance. Emergence of cotyledons above the soil level was taken as a criterion for seed germination. Seed germination was recorded till 30th day after sowing and the survival of the pregeny was recorded at weekly intervals.

The experiments in field conditions were carried out in two sets. In each set, 500 seeds were sown per treatment in randomized microplots at the rate of 100 seeds per replication. There were five replications in each of the seven treatments. Hundred seeds per microplot were sown in ten rows. In each row ten seeds were planted at equal distance. Precaution was taken to plant the seeds at uniform depth and distance.

In the first set of experiment, from the 500 seeds sown, seed germination, plant survival and the morphological modifications such as lodging, stem bifurcations, variegation and fasciated shoots were recorded. The germination and survival percentages were calculated as follows :-

$$\text{Germination percentage} = \frac{\text{No. of seed germinated}}{\text{No. of seeds sown}} \times 100$$

$$\text{Survival percentage} = \frac{\text{No. of plants survived upto the time of harvest}}{\text{No. of seeds germinated}} \times 100$$

In the second set of experiment, out of 500 seeds sown, twentyfive plants were uprooted per treatment selecting five plants at random from each replication for the growth analysis and biomass studies at different intervals, when the seedlings attained the age of 15, 30, 45, 60 and 120 days. At each turn of sampling, 5 individuals were studied for growth analysis using the parameters fresh and dry weight of the plants, number of primary branches, hypocotyl length, root length and shoot length. However, at maturity that is after 120 days the above growth determinations were made using 15 plants per replicate instead of 5 used so far.

Cotyledonary area was obtained by tracing thirty samples per treatment on a graph paper and by counting the small squares ($1mm^2$) enclosed by the outline of each cotyledon traced. At the periphery, where the outline of a particular cotyledon covered half or more area of a small square it was counted as one small square.

Number of floral branches, number of fruits per plant, number of seeds per plant, weight of one thousand seeds per treatment were also recorded at maturity from fifteen plants per replication.

Floral morphology - To study the effect of gamma-rays on the

various parts of the flowers. 100 randomly selected flowers were collected in each treatment at the rate of 20 flowers per replication taking two random flowers from ten plants in each replication. The following floral parts were measured in centimeters on an ordinary scale and with the help of a magnifing glass if required :

Length of stalk (Pedicel)
Size of calyx
Size of corolla
Size of carpel

Pollen-fertility - The pollen fertility of the progenies of the different treatments was determined in freshly opened flowers, using stainability of pollen grains in 1% acetocarmine as an index. Turgid and deeply stained pollen grains were considered viable and fertile while unstained and shrunken ones as non-viable and sterile. For each treatment five thousand pollen grains were studied from twentyfive different plants taking pollen grains from two flowers per plant and five different plants in each replication. In each replication 1000 pollen grains were examined.

Maceration of vessels and fibres - At maturity, the internodal pieces of the same order, of the plants of different treatments, were fixed in F.A.A. for anatomical studies. The stem pieces were trimmed to 2 cm size and were cut into slices of 1 mm thickness in longitudinal plane for maceration. After a thorough washing

in running water, the slices were given a hot treatment with 40% HNO3 (Ghouse and Yunus, 1972) which yielded different xylem components in macerated form. The xylem vessels and fibres were hand picked from the macerated mass and mounted in glycerol, after staining in iron-alum haematoxylin.

The individual elements of vessels and fibres were measured by an ocular scale. The average length of vessels and fibres were calculated from readings obtained on 300 randomly selected elements of each category per treatment.

Oil extraction - Oil was extracted from thoroughly cleaned and well dried crushed sample of seeds. The crushed seeds were extracted repeatedly with light petroleum (40-60°C) in a Soxhlet apparatus. The solvent was removed under reduced pressure/nitrogen to find out the oil content of the seeds. (Anonymous, 1973).

Methyl esters - Fatty acid samples were refluxed for 1 hr in a large excess of absolute methanol containing 1% sulphuric acid. In each case resulting mixture was diluted with water, chilled in an ice-bath and then extracted repeatedly with diethyl ether. Combined extracts were dried over sodium sulphate and evapurated in vacuo.

Gas-liquid chromatography - Gas-liquid chromatography of the methyl esters was carried out using a Perkin-Elmer (Model 154)

gas chromatograph using 2x3/16" column of Silicone (SE 30, 2%) and a 8x4/16" column of polyester (Diethylene glycol succinate, 15% on chromosorb W, 45-60 mesh). Temperatures at the injection port, detector block and column were 290°C, 260°C and 190°C, respectively. Attenuation 4, bridge current 150 m amp. and chart speed 30 inches/ hr. Hydrogen flow rate 70 ml/min.

Statistical analysis of the data - The data obtained during the present study has been analysed statistically, wherever it was considered necessary to draw precise conclusions.

Analysis of variance was carried out by adopting one way classification. The five means obtained from the five replications in each treatment for a particular parameter were used in the analysis of variance. F-ratio was obtained by dividing the Mean sum of Squares due to treatment by Mean sum of squares due to error. When the value of f-ratio was found greater than the given t-value at 5% level of significance at the required degrees of freedom, the treatment was considered significant and then the data was analysed further for comparing the performance of different treatments among themselves by applying Duncan's Multiple Range Test (Walpole and Myers, 1978).

$$R_p = rp \sqrt{\frac{s^2}{n}}$$

where,

R_p = Least significant range
rp = Least significant studentized range
s^2 = Error mean square obtained in analysis of variance.
n = Number of observations per treatment.

OBSERVATIONS

OBSERVATIONS

Germination :

The rate as well as the total amount of germination was studied under potted and field condition in both, the untreated and treated lots of seeds. The emergence of cotyledons to the soil surface was taken as the criterion of germination.

Pot condition - The initiation of germination under pot condition in control, 25 and 50 krad treatments was observed seven days after sowing, while the same was observed eight days after sowing in higher doses like 75, 100, 125 and 150 krad treatments. The initial germination percentage was, however, low in seeds which received higher intensities of gamma-rays, compared to control, 25 and 50 krad treatments. The germination process continued for three to four days under low intensity treatments whereas under high doses, it prolonged for five days. But no such delay in germination was, however, observed in M_2 generation.

There was no marked difference in germination percentage of the different treatments compared to control except in the higher dosages like 125 and 150 krad in which the germination percentage was considerably low, as they recorded 89.00 and 87.00% respectively (Table 1).

The seedling survival percentage in control, 25, 50, 75, 100, 125 and 150 krad treatments was 97.95, 95.95, 96.00, 93.74, 93.67, 71.71 and 64.48 respectively.

In M_2 generation, 98.00% seed germination was recorded in control. In 25, 50, 75, 100, 125 and 150 krad treatments, the germination percentage was found to be 98.00, 96.00, 94.00, 92.00, 95.00 and 93.00 respectively. There was no marked difference in plant survival percentage in all the treatments including that of control.

Field condition - Seed germination in field condition was first observed five days after sowing. The initial germination percentage was, however, considerably low in higher dosages. The germination process was completed within three days after its initiation in all the treatments.

In M_1 generation, the untreated seeds showed 94.60% germination whereas the same was recorded as 95.00, 94.00, 92.80 and 90.20% in these seeds which received 25, 50, 75 and 100 krads respectively. The seed germination in the other two treatments was slightly suppressed and it was found to be 85.40 and 82.00% in 125 and 150 krad treatments respectively (Table 1).

Control plants showed 97.67% survival whereas it was 94.53, 92.13, 88.58, 85.37, 76.11 and 57.80% in 25, 50, 75, 100, 125 and 150 krad treatments respectively. Plant survival

Table : 1 Effect of different acute doses of gamma-rays on seed germination and plant survival percentage in Linum usitatissimum L. under Field (F.C.) and Pot conditions (P.C.).

Treatment		M_1 Generation		M_2 Generation	
		Germination	Survival	Germination	Survival
Control	F.C.	94.60	97.67	96.00	97.92
	P.C.	97.00	97.95	98.00	98.00
25 Krad	F.C.	95.00	94.53	96.00	97.08
	P.C.	96.00	95.95	98.00	96.95
50 Krad	F.C.	94.00	92.13	95.40	96.65
	P.C.	97.00	96.00	96.00	95.84
75 Krad	F.C.	92.80	88.58	94.00	96.81
	P.C.	95.00	93.74	94.00	96.84
100 Krad	F.C.	90.20	85.37	92.60	96.33
	P.C.	93.00	93.67	92.00	94.56
125 Krad	F.C.	85.40	76.11	93.00	95.91
	P.C.	89.00	71.71	95.00	94.89
150 Krad	F.C.	82.00	57.80	90.40	95.35
	P.C.	87.00	64.48	93.00	93.51

percentage in M_1 generation therefore, decreased with increasing intensities of gamma-rays (Fig. 1).

More than 90% seed germination was recorded in all the treatments including that of control in M_2 generation and there was practically no difference in the plant survival percentage of control and in different treatments (Fig. 2).

Growth :

The growth study was carried out under field conditions in microplots selected in a randomized pattern (Plate I-B). The rate of seedling survival was also studied in pots (Plate II) under the protected condition of a green house.

The rate of growth of treated and the untreated progenies was studied at fortnightly intervals using hypocotyl elongation, cotyledonary expansion, root-shoot increment, branch, leaf and biomass production as parameters.

Hypocotyl - The length of hypocotyl showed a decreasing trend under different treatments depending upon the intensity of gamma-rays, the decrease being in linear proportion to the dosage. In the untreated plants, the length of hypocotyl happened to be at its maximum, while in the treated ones, it invariably remained shorter compared to control. Statistical analysis of the data obtained on the hypocotyl length of various treatments revealed that the difference in length of hypocotyl region of

Figure 1: Effect of different acute doses of gamma-rays on seed germination and seedling survival of *Linum usitatissimum* L. var. neelum in M_1 generation.

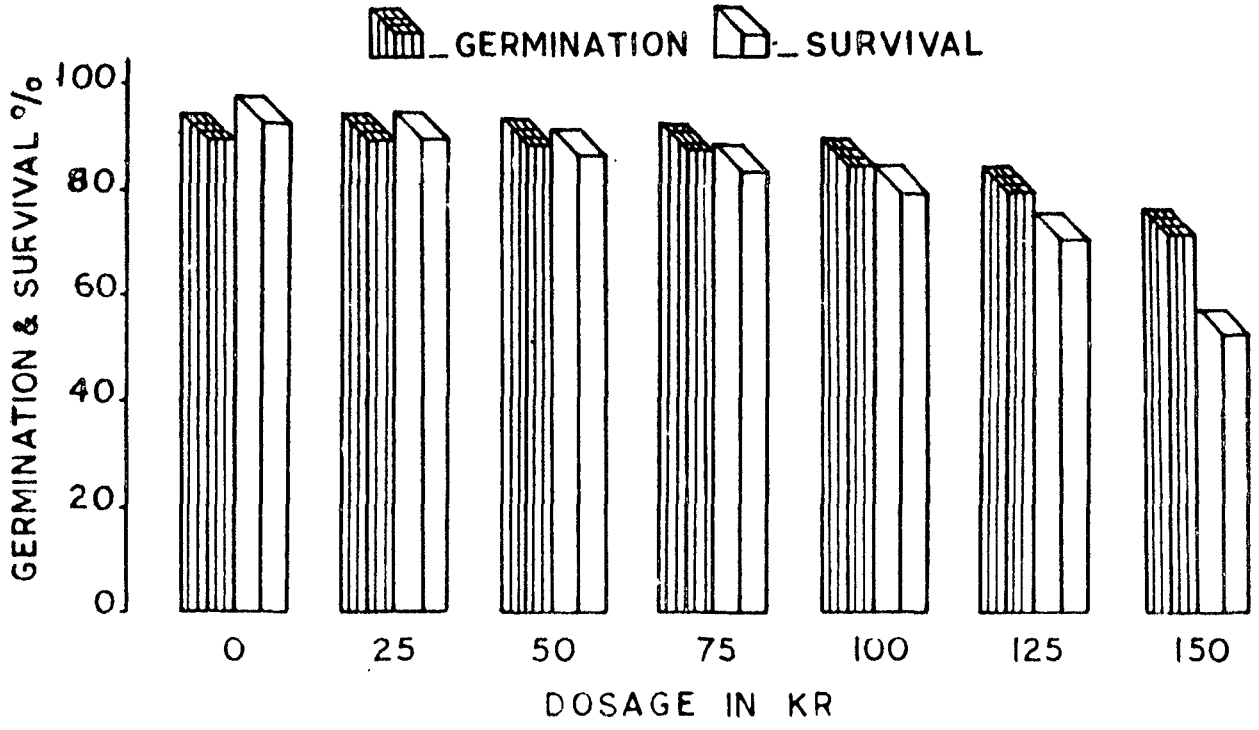
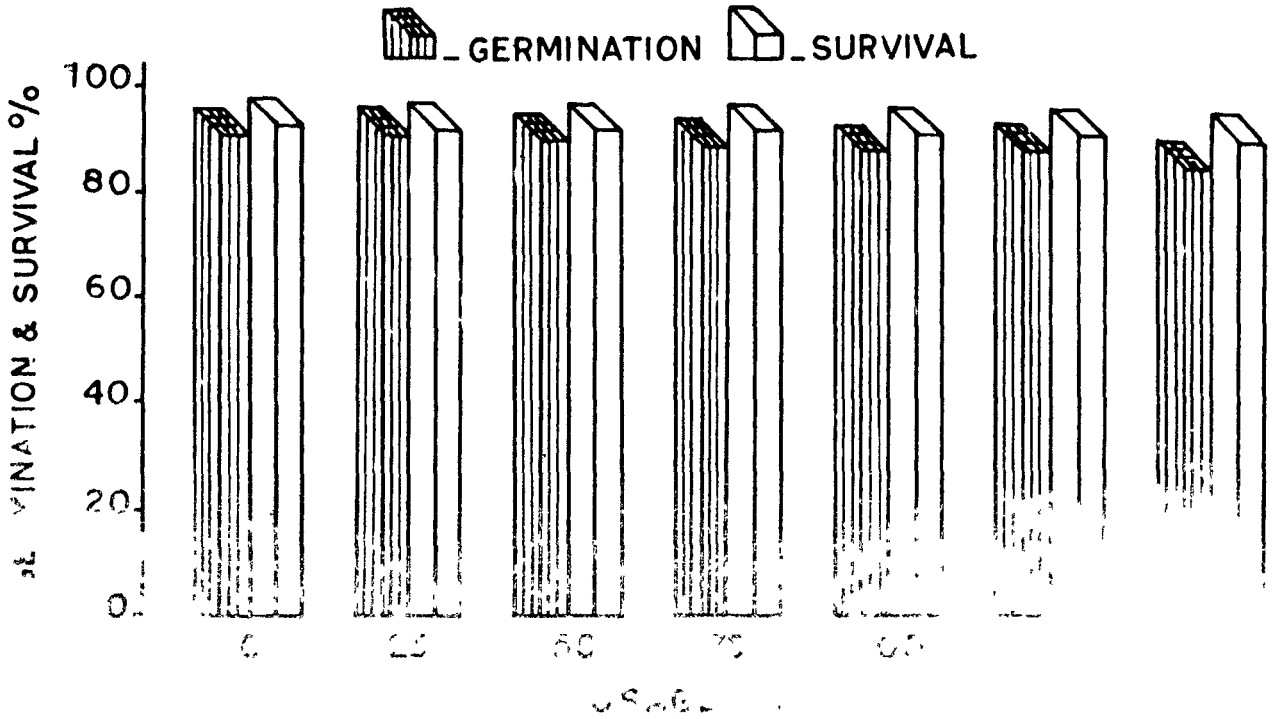

GERMINATION
SURVIVAL
GERMINATION & SURVIVAL %
100
80
60
40
20
0
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 1

Figure 2: Effect of different acute doses of gamma-rays on seed germination and seedling survival of *Linum usitatissimum* L. var. neelum in M_2 generation.


GERMINATION
SURVIVAL
100
80
60
40
20
0
& SURVIVAL %

the different treatments significantly differ from that of control. Among the treated ones, the hypocotyl length did not differ to any significant level under 25 and 50 krad treatments on one hand and under 100 and 125 krad treatments on the other. However, the 75 and 150 krad treatments differed significantly from all other treatments (Table 2).

In M_2 generation, the hypocotyl length did not follow the same trend as it did in M_1 generation. Under 25 krad treatment, the plants developed a slightly shorter hypocotyl region compared to that of control, whereas under 50 and 75 krad treatments it happened to be slightly longer than that of control. Under 100 krad treatment, the hypocotyl region was found to be slightly shorter than that of control and at the same time it had been found to be slightly longer than in 25 krad treatment. Under 125 and 150 krad treatments, the plants produced a hypocotyl region which fell shorter than that developed under 25 krad treatment (Table 3).

A comparison of hypocotyl regions of plants of M_1 and M_2 generations under corresponding treatments had shown that in M_2 generation the plants had produced a longer hypocotyl than in M_1 generation. The difference in length between M_1 and M_2 generations was found to be higher under high intensity doses than in the low intensity ones, indicating a higher rate of recovery in the former than in the latter.

Cotyledons - The mean area per cotyledon in control plants was found to be 1.14 square centimeters (Table 2). The area per cotyledon in plants of 25, 50 and 75 krad treatments showed an increase over control and the degree of stimulation in these treatments was 1.8, 5.3 and 6.1 percent respectively although statistical analysis rated these three treatments at par with that of control. Further increase in the intensity of gamma-rays above 75 krad showed an apparent decrease. The decrease over control in 100 and 125 krad treatments was recorded to be 7.9 percent while in 150 krad treatment it was 3.5 percent, again the difference being not significant under the rules of statistics.

The area per cotyledon in plants of control of M_2 generation showed 1.14 square centimeters. The area per cotyledon in the first four treatments was 1.15, 1.17, 1.14 and 1.14 square centimeters respectively. The same was recorded as 1.12 square centimeters in 125 and 150 krad treatments (Table 3).

The cotyledonary area of M_2 generation in general had shown that the apparent differences recorded in M_1 generation do not exist in the M_2 generation.

The mean fresh weight per cotyledon in control plants of M_1 generation was found 0.0393 gm. In 25, 50, 75, 100, 125 and 150 krad treatments, it was recorded to be 0.0425, 0.0476, 0.0452, 0.0410, 0.0421 and 0.0506 gm respectively (Table 2).

The mean fresh weight per cotyledon in treated plants was found significantly more, compared to that of control except in case of 100 krad treatment. The highest increase in fresh weight per cotyledon over control was recorded 28.8 percent in 150 krad treatment followed by 21.1 and 15.0 percent in 50 and 75 krad treatments respectively. The increase in fresh weight per cotyledon in 25 krad treatment was recorded to be 8.1 percent, whereas it was 4.3 and 7.1 percent in 100 and 125 krad treated plants respectively.

In M_2 generation, the 25, 50 and 150 krad treated plants showed 11.8, 16.8 and 21.6 percent decrease over the control in their fresh weights of cotyledons whereas 75, 100 and 125 krad treatments showed 16.8, 9.0 and 1.0 percent increase over control.

The dry weight analysis of treated plants had revealed that it did not differ to significant level among the different treatments as well as to that of control except in case of 150 krad treatment in which the cotyledonary dry weight surpassed that of all other treatments and the control but to a significant level compared to 75, 100 and 125 krad treatments.

The fresh weight and dry weight ratio of the cotyledons of control plant in M_1 generation was 8.5 whereas it was 9.2, 10.1, 10.8, 10.3, 10.5 and 9.5 in 25, 50, 75, 100, 125 and 150 krad treatments respectively (Table 2).

Table : 2 Effect of different acute doses of gamma-rays on hypocotyl and cotyledons of Linum usitatissimum L. in M_1 generation.

Treatment	Hypocotyl	Cotyledon			
	Length (cm)	Area $(cm)^2$	F.W. (gm)	D.W. (gm)	F.W./ D.W.
Control	4.34 a ±0.11	1.14 ab ±0.05	0.0393 e ±0.0013	0.0046 ab ±0.0001	8.5
25 Krad	4.00 b ±0.19	1.16 ab ±0.12	0.0425 d ±0.0019	0.0046 ab ±0.0002	9.2
50 Krad	3.70 b ±0.28	1.20 a ±0.07	0.0475 b ±0.0014	0.0047 ab ±0.0001	10.1
75 Krad	3.36 c ±0.33	1.21 a ±0.05	0.0452 c ±0.0017	0.0042 b ±0.0002	10.8
100 Krad	2.76 d ±0.23	1.05 b ±0.05	0.0410 de ±0.0019	0.0040 b ±0.0002	10.3
125 Krad	2.72 d ±0.28	1.05 b ±0.09	0.0421 d ±0.0016	0.0040 b ±0.0002	10.5
150 Krad	2.18 e ±0.31	1.10 ab ±0.12	0.0506 a ±0.0020	0.0053 a ±0.0002	9.5

F.W. = Fresh Wieght; D.W. = Dry weight

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 3 Effect of different acute doses of gamma-rays on hypocotyl and cotyledons of Linum usitatissimum L. in M_2 generation.

Treatment	Hypocotyl	Cotyledon			
	Length (cm)	Area $(cm)^2$	F.W. (gm)	D.W. (gm)	F.W./ D.W.
Control	4.48 ±0.19	1.14 ±0.05	0.0398 ±0.0014	0.0048 ±0.0002	8.3
25 Krad	4.22 ±0.19	1.15 ±0.06	0.0351 ±0.0011	0.0041 ±0.0001	8.6
50 Krad	4.56 ±0.11	1.17 ±0.06	0.0331 ±0.0013	0.0039 ±0.0002	8.5
75 Krad	4.60 ±0.26	1.14 ±0.04	0.0465 ±0.0016	0.0058 ±0.0002	8.0
100 Krad	4.38 ±0.38	1.14 ±0.05	0.0434 ±0.0021	0.0056 ±0.0003	7.8
125 Krad	4.04 ±0.21	1.12 ±0.04	0.0402 ±0.0015	0.0048 ±0.0002	8.4
150 Krad	3.58 ±0.23	1.12 ±0.03	0.0312 ±0.0022	0.0046 ±0.0003	6.8

F.W. = Fresh weight ; D.W. = Dry weight

: ± S.E.

The fresh weight and dry weight ratios of the cotyledons of treated plants showed slightly higher values as compared to control plants of M_1 generation, indicating that the cotyledons of treated seedlings had developed the ability, to retain more water in reaction to gamma-rays. The plants of M_2 generation, however, did not show much difference in their fresh weight and dry weight ratios of the cotyledons (Table 3).

Root - The length of the roots in control and in different treated plants were measured after the seedlings attained the age of 15, 30, 45, 60 and 120 days. The control plants showed slightly better growth as well as a higher rate of growth than the treated seedlings of the corresponding age. The results obtained in the present study show that the control plants by the time they attained the age of 60 days, had almost established root system as they did not show any further increase in the length of root.

The amount and the rate of growth of roots in the treated seedlings showed a set back at all levels of observation compared to control. The suppression in growth was found to be of minor magnitude in lower dosages where as, it was quite considerable and significant in doses like 100, 125 and 150 krad treatment. However, unlike in control, the increase in root length continued even after 60 days in the treated seedlings (Table 4).

Table : 4 Rate of root elongation (cm) in M_1 generation of *Linum usitatissimum* L. under the different gamma-ray treatments.

Treatment	Days After Germination				
	15	30	45	60	120
Control	7.40 a ±0.09	9.84 a ±0.96	11.42 a ± 0.82	12.42 a ± 1.42	12.50 a ± 0.94
25 Krad	6.40 abc ±1.07	8.26 a ±1.80	10.06 ab ± 1.23	10.18 b ± 1.79	12.14 ab ± 1.08
50 Krad	6.66 ab ±1.44	8.84 a ±1.02	9.78 ab ±1.54	10.28 b ± 1.96	10.84 bc ± 1.84
75 Krad	6.18 abc ±1.60	8.36 a ±0.89	9.04 bc ± 1.34	9.92 b ± 1.30	10.32 c ± 0.44
100 Krad	5.62 bc ±1.21	7.66 ab ±1.30	8.10 bc ± 1.49	8.30 c ± 1.25	9.42 cd ± 1.33
125 Krad	5.70 abc ±1.16	6.26 bc ±1.62	7.26 cd ± 1.48	7.94 cd ± 1.26	8.30 cd ± 1.25
150 Krad	4.84 c ±0.95	5.24 c ±2.18	6.08 d ± 1.84	6.76 d ± 1.10	6.94 e ± 0.83

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 5 Rate of root elongation (cm) in M_2 generation of Linum usitatissimum L. under different gamma-ray treatments.

Treatment	Days After Germination				
	15	30	45	60	120
Control	7.60 ±0.78	8.58 ±1.20	10.96 ± 0.78	12.22 ± 1.00	12.76 ± 0.51
25 Krad	7.12 ±0.54	8.66 ±0.62	10.12 ± 0.98	12.28 ± 1.23	12.80 ± 0.67
50 Krad	7.50 ±0.60	8.70 ±0.51	9.90 ± 1.10	12.16 ± 1.07	12.66 ± 0.69
75 Krad	7.46 ±0.72	8.24 ±0.87	9.48 ± 0.83	11.00 ± 1.02	11.40 ± 0.49
100 Krad	7.00 ±0.83	8.14 ±0.75	8.98 ± 0.98	10.02 ± 0.83	11.10 ± 1.23
125 Krad	6.70 ±0.79	7.22 ±1.37	7.52 ± 0.44	9.18 ± 0.86	10.56 ± 0.89
150 Krad	6.32 ±0.79	7.10 ±0.98	7.71 ± 1.07	9.00 ± 0.99	9.88 ± 1.12

± S.E.

In M_2 generation, the root length showed an increase compared to M_1 generation in all treatments. In lower doses like 25 and 50 krads, the root length attained the level of control plants, where as in others they remained lower to the control. The root development in M_2 generation also showed the same trend as in M_1 generation with a proportionate decrease to the amount of radiation (Table 5).

Shoot - In a comparison of shoot length of control with that of 25 and 50 krad treatments in 15 day old seedlings of M_1 generation it was found that they did not differ among themselves to any significant level, while 100 krad treatment had shown a significant difference from that of control, 25 and 50 krad on one hand and 150 krad treatment on the other. However, it had shown no significant difference with its immediately lower and higher dosages that is 75 and 125 krad treatments. The differences between control and 150 krad was found to be highly significant at 5% significance level by Duncan's Multiple Range Test (Table 6).

In 30 day old seedlings, the shoot length differences of lower dosages that is upto the extent of 75 krad treatment, did not show any significant difference, although they were found to be significantly different from control (Plate III). The 100 and 125 krad treatments were also not significantly different among themselves but were significantly different

from rest of the doses. Highest difference was found between control and the highest dose that is 150 krad treatment.

In 45 day old seedlings, the shoot length of control, 25 and 50 krad treatments were found to be almost the same, as the difference among them did not vary to any significant level, although the height of control plants was apparently higher than others. The plants of 75 krad treatment developed a height some what less than those of 25 and 50 krad treatments but statistically the difference did not go to the extent of any significance. The plants of the other treatments that is 100 to 150 krads grew more or less to the same height but it was significantly less to that of lower doses and control.

Among the 60 day old seedlings, for the first time, 25 krad showed slightly better growth over control but the magnitude of the stimulation being only meagre and not statistically significant at 5% level.

In 120 day old plants, the mean shoot length was not significantly different among the control, 25, 50 and75 krad treatments although the treated ones showed some degree of stimulation over control. However, the stimulation in shoot length, was not found significant at 5% level. On the other hand a marked reduction in shoot length was observed in 100, 125 and 150 krad treatments and the difference was significant compared to control and the lower dosages. The 125 and 150 krad treatments showed no significant difference between themselves.

The trend of sheet growth in M_2 generation was more or less the same as that of M_1 generation. The lower doses had a slight edge over the control (Table 7). The M_2 progeny showed considerable recovery from the suppressive effect of irradiation treatment.

Branches - The number of branches and the time of branching were noted at fortnightly intervals in the treated as well as in control. It was found at the initial stage that the control and the 25 krad treatment showed almost the same number of branches with the latter having a slight margin over the former. In 50 and 75 krad treatments, the plants initiated branching at this stage but to a very poor extent, while in the other treatments no branching occurred at this stage. Statistical analysis has proved that in cases of 50 and 75 krad treatments, the number of branches developped, happend to be significantly less compared to control and 25 krad treatments (Table 8).

In the next stage of observation that is in 30 day old seedlings, the branching improved in 50 krad treatment a little above to the level of control and 25 krad treatment. The number of branches at this stage of development of seedlings in 50 krad treatment apparently showed a higher number but the difference was found to be not significant over the control on statistical analysis at 5% level. In other treatments, the plants exhibited branching but only to a poor extent.

Table : 6 Rate of shoot elongation (cm) in M_1 generation of *Linum usitatissimum* L. under the different gamma-ray treatments.

Treatment	Days After Germination				
	15	30	45	60	120
Control	13.20 a ± 0.40	22.82 a ± 2.39	33.76 a ± 3.61	48.66 a ± 3.03	60.79 b ± 0.83
25 Krad	12.38 a ± 0.99	20.32 b ± 1.04	32.30 ab ± 1.62	49.66 a ± 4.44	62.67 b ± 1.07
50 Krad	12.72 a ± 1.55	19.40 b ± 1.64	31.44 ab ± 1.87	42.00 b ± 2.00	86.82 a ± 1.15
75 Krad	10.54 b ± 1.29	16.86 b ± 0.76	29.30 b ± 1.17	40.82 b ± 3.37	85.20 a ± 3.68
100 Krad	9.72 bc ± 0.64	15.68 c ± 1.40	24.24 c ± 4.64	30.10 c ± 2.72	72.18 c ± 1.00
125 Krad	8.90 c ± 0.95	14.74 c ± 2.00	20.90 c ± 2.70	26.44 d ± 1.71	61.80 d ± 1.07
150 Krad	6.22 d ± 0.83	9.04 d ± 1.65	20.46 c ± 3.27	23.00 d ± 2.79	58.06 e ± 1.09

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 7 Rate of sheet elongation (cm) in M_2 generation of *Linum usitatissimum* L. under the different gamma-ray treatment.

Treatment	Days After Germination				
	15	30	45	60	120
Control	12.10 ± 0.69	21.70 ± 2.32	31.92 ± 2.18	49.90 ± 2.76	82.58 ± 3.75
25 Krad	11.80 ± 0.66	22.78 ± 1.47	32.14 ± 1.89	55.60 ± 4.98	82.90 ± 4.35
50 Krad	12.62 ± 0.79	21.40 ± 1.53	30.52 ± 1.38	53.50 ± 3.69	86.00 ± 1.62
75 Krad	12.06 ± 1.50	20.70 ± 1.59	29.62 ± 2.05	51.60 ± 5.06	83.44 ± 2.79
100 Krad	10.60 ± 1.01	18.80 ± 1.43	27.88 ± 2.43	48.60 ± 3.23	77.28 ± 5.29
125 Krad	10.30 ± 1.13	16.64 ± 1.78	26.86 ± 1.71	43.40 ± 6.69	73.00 ± 6.66
150 Krad	9.40 ± 1.20	14.84 ± 1.64	22.08 ± 2.03	38.44 ± 7.93	71.12 ± 8.25

: ± S.E.

At the stage of 45 day growth, the 25 krad treatment showed the maximum number of branches compared to all the other treatments and the control. The number of branches under this treatment showed a significant difference over others including the control but not compared to 50 krad treatment. In the rest of the treatments, the number of branches remained significantly less.

At 60 day stage, in control and in the two lower doses of 25 and 50 krads, the number of branches did not differ to any significant level among themselves, while the rest followed the same trend as in the other stages of observations.

At the final stage of observation the branching level remained the same as in 60 day old plants (Table 8).

In M_2 generation branching occurred in all treatments except in 150 krads, in 15 day old seedlings. Branching initiated in the above in 30 day old plants. In general, the number of branches per plant in all treatments remained higher compared to M_1 generation, except in 25 and 50 krad treatments in which the second generation showed a less number of branches compared to M_1 generation. However, the number of branches per plant in all treatments including the lower ones, remained poor compared to control (Table 9).

Leaves - The number of leaves per plant was observed at fortnightly intervals. It was found that the number of leaves

Table : 8 Rate of branch development in M_1 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Days After Germination				
	15	30	45	60	120
Control	1.68 a ±0.11	2.08 a ±0.23	2.64 bc ±0.26	3.12 a ±0.23	3.64 a ±0.26
25 Krad	2.00 a ±0.20	2.00 a ±0.24	3.08 a ±0.27	3.20 a ±0.57	3.80 a ±0.37
50 Krad	0.92 b ±0.19	2.24 a ±0.17	2.88 ab ±0.23	3.00 ab ±0.62	4.12 a ±0.41
75 Krad	0.44 c ±0.26	1.36 b ±0.33	2.28 c ±0.33	2.44 b ±0.56	2.68 b ±0.54
100 Krad	-	0.84 c ±0.17	1.84 d ±0.17	1.76 c ±0.26	2.40 bc ±0.57
125 Krad	-	0.20 d ±0.14	1.32 e ±0.48	1.32 cd ±0.30	1.92 c ±0.58
150 Krad	-	0.16 d ±0.09	0.72 f ±0.30	0.68 d ±0.30	1.08 d ±0.87

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 9 Rate of branch development in M_2 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Days After Germination				
	15	30	45	60	120
Control	1.96 ±0.17	2.12 ±0.30	2.92 ±0.41	3.28 ±0.59	3.84 ±0.48
25 Krad	1.80 ±0.31	2.00 ±0.42	2.44 ±0.43	2.52 ±0.48	3.16 ±0.38
50 Krad	1.72 ±0.33	2.20 ±0.28	2.36 ±0.48	2.48 ±0.41	2.76 ±0.62
75 Krad	1.48 ±0.23	1.84 ±0.29	2.32 ±0.54	2.40 ±0.47	3.00 ±0.63
100 Krad	0.56 ±0.36	1.28 ±0.41	2.04 ±0.65	2.28 ±0.36	2.60 ±0.73
125 Krad	0.12 ±0.11	0.60 ±0.31	1.64 ±0.38	1.80 ±0.63	2.84 ±0.64
150 Krad	-	0.20 ±0.14	1.40 ±0.49	1.68 ±0.54	2.56 ±0.38

: ± S.E.

increased with the growing height of the plants. In M_1 generation the number was found to be less in the treated progenies compared to control (Table 10).

In M_2 generation, the number of leaves per plant followed the same trend as in M_1 generation but at no stage, the number of leaves of the treated progenies exceeded that of control (Table 11).

Upper ground biomass - The biomass of different treated progenies and the control was calculated at fortnightly intervals. The upper ground mass under fresh condition showed a decreasing tendency from control to the treated ones with the decrease following a gradual decline towards higher intensity. In 15 day old seedlings, the biomass of control and 25 krad treatment was found to be not different to a significant level and at the same time the 25 krad and 50 krad treatments also did not differ from each other. However, the biomass of control plants was significantly higher than those of 50 krad. All the other treatments from 75 to 150 krads showed significantly lesser biomass than the control as well as the 25 and 50 krad treatments.

In 30 day old seedlings, the upper ground biomass of control plants was significantly higher than the treated ones and among the latter, the first two treatments of 25 and 50 krad did not vary to any significant level among themselves.

Table : 10 Rate of leaf production in M_1 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Days After Germination			
	15	30	45	60
Control	48.60 a ± 1.34	139.96 a ± 4.73	278.40 a ± 12.67	352.44 b ± 11.23
25 Krad	36.00 b ± 2.16	113.60 b ± 2.62	248.68 b ± 9.49	393.76 a ± 13.34
50 Krad	30.64 c ± 0.86	101.20 c ± 5.50	266.16 a ± 7.47	322.84 c ± 16.94
75 Krad	28.04 d ± 0.52	76.16 d ± 4.71	198.80 c ± 18.21	269.40 d ± 17.68
100 Krad	21.28 e ± 0.81	53.88 e ± 1.91	130.00 d ± 10.03	220.32 e ± 19.28
125 Krad	20.20 e ± 0.37	47.40 f ± 1.29	111.80 e ± 7.26	209.48 e ± 20.11
150 Krad	17.00 f ± 0.45	40.00 g ± 2.62	92.20 f ± 2.38	164.36 f ± 4.54

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 11 Rate of leaf production in M_2 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Days After Germination			
	15	30	45	60
Control	46.92 ± 1.13	138.62 ± 5.71	274.64 ± 8.97	350.80 ± 11.75
25 Krad	29.86 ± 0.94	124.50 ± 4.83	206.32 ± 9.10	325.20 ± 11.97
50 Krad	28.08 ± 1.16	118.04 ± 6.20	176.60 ± 8.28	310.64 ± 7.37
75 Krad	35.98 ± 0.94	127.36 ± 6.60	183.52 ± 4.79	278.10 ± 8.60
100 Krad	30.08 ± 1.59	116.24 ± 3.18	108.10 ± 7.95	239.86 ± 6.27
125 Krad	26.34 ± 1.27	83.40 ± 5.51	94.46 ± 11.73	158.52 ± 8.27
150 Krad	21.42 ± 2.10	80.92 ± 4.46	91.68 ± 8.58	143.24 ± 9.22

: ± S.E.

The 75 krad treatment yielded a biomass which was found to be not statistically significant from that of 50 krad treatment, although it did vary to a significant level from that of 25 krad treatment. The high intensity treatments of 100, 125 and 150 krad also did not show any difference to any significant level among themselves but they did differ significantly from the first three treatments.

At 45 day stage of growth, the control plants and the first two treatments showed the same fresh weight, the 50 krad treatment being some what less from that of 25 krad treatment, happened to be a little higher than 75 krad treatment. The last three treatments followed the same trend as in the 30 day old plants (Table 12).

At 60 day stage, highest biomass was produced by 25 krad treatment, although it was not statistically significant from that of control. Among the rest, the 50, 75 and 100 krad treatments produced more or less the same fresh weight without any significant difference among themselves, while the last two treatments fell in the same category of biomass production (Table 12).

When the upper ground biomass was calculated on dry weight basis at different stages of plant growth, it was found that the first three treatments at the initial stage produced almost the same dry matter and on analysis it proved to be

significantly less compared to that of control except the first treatment of 25 krad. Among the rest, the 100 krad treatment produced a moderate amount of biomass while 125 and 150 krad treatments produced a poor dry matter.

At the 30 day old stage, the control produced significantly higher dry weight than the treated ones. Among the treated ones, the first two treatments produced higher biomass than the others. The last three treatments experienced at this stage, a high set-back and produced a very poor amount of dry weight.

In 45 day old plants, the control and the 25 krad treatment yielded the highest dry mass, although it did not show significant difference with the one produced by 50 krad treatment. The 75 krad treatment also produced almost the same amount to that of 50 krad treatment but with some what lesser margin. The rest three high intensity treatments showed no difference among themselves in dry matter production but the amount being far less than the others.

At 60 day old stage the dry weight of shoot system had revealed that the dry matter produced by control plants and that of 25 krad treatment was of the same level, whereas what was produced by 50, 75 and 100 krad treatments, was not significantly different from one another. In 125 krad treatment, the biomass production fell at the same category of 100 krad treatment on one hand and that of the 150 krad treatment on the other (Table 13).

Table : 12 Rate of upper-ground biomass production in terms of fresh weight (gm) of M_1 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.6059 a ±0.0825	1.6417 a ±0.3462	5.3240 a ±2.1352	8.6626 a ±3.1204
25 Krad	0.5330 ab ±0.1112	1.3084 b ±0.1524	4.8304 a ±0.7161	8.8224 a ±2.1828
50 Krad	0.4906 bc ±0.0923	1.2412 bc ±0.3693	4.2755 ab ±0.5318	6.3781 b ±1.6973
75 Krad	0.3845 c ±0.0353	0.9654 c ±0.1905	3.0958 b ±0.9119	4.8639 b ±2.1742
100 Krad	0.2885 d ±0.0234	0.6475 d ±0.1266	1.5834 c ±0.8601	3.6035 bc ±1.6282
125 Krad	0.2578 d ±0.0230	0.6340 d ±0.1638	1.1780 c ±0.3439	1.8376 c ±0.7939
150 Krad	0.2364 d ±0.0333	0.3408 d ±0.0461	1.1322 c ±0.2121	1.2991 c ±0.3926

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table: 13 Rate of upper-ground biomass production in terms of dry weight (gm) of M_1 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0659 a ±0.0114	0.2426 a ±0.0441	0.7107 a ±0.2674	1.7275 a ±0.5686
25 Krad	0.0567 ab ±0.0153	0.1915 b ±0.0126	0.6592 a ±0.1000	1.7421 a ±0.3749
50 Krad	0.0473 bc ±0.0092	0.1818 bc ±0.0399	0.6196 ab ±0.0621	1.1883 b ±0.3671
75 Krad	0.0522 b ±0.0059	0.1446 c ±0.0286	0.4683 b ±0.1130	1.0536 bc ±0.3610
100 Krad	0.0369 cd ±0.0064	0.0926 d ±0.0216	0.2798 c ±0.1430	0.8331 bcd ±0.3295
125 Krad	0.0277 de ±0.0036	0.1057 d ±0.0313	0.2080 c ±0.0613	0.5716 cd ±0.2385
150 Krad	0.0188 e ±0.0058	0.0475 e ±0.0097	0.2043 c ±0.0309	0.3733 d ±0.1322

1 ± S.E.

2 Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

The analysis of biomass production by M_2 generation had indicated that the upper ground biomass at the first stage of plant growth determined on 15 day old plants on fresh weight basis showed a trend similar to that of first generation in having a gradual decrease of biomass from control to treated ones (Table 14). The biomass produced by the 15 day old plants in the second generation when compared to that of first generation in respective treatments, had revealed that the fresh mass happened to be quite less in the second generation. At the second stage of observation, the biomass on fresh weight basis surpassed the first generation but following the same trend as that of the previous stage in showing a decreasing trend from lower to higher dosage. In 45 day old stage, the fresh weight showed a decrease in the first two treatments compared to that of first generation. In the other treatments there had been a marked improvement in the biomass production over the first generation. In the analysis of 60 day old plants, the biomass production showed a remarkable increase over the first generation under all treatments, although the higher doses recorded many times increase over their counterpart of the first generation, indicating the high recovery rate of the second generation especially at higher levels of irradiation treatments.

When the same was analysed quantitatively on dry weight basis, it was found that the general trend of biomass production had followed more or less the same trend which was noticed on the fresh weight basis with some minor fluctuations (Table 15).

Table : 14 Rate of upper-ground biomass production in terms of fresh weight (gm) of M_2 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.5692 ±0.0603	1.6910 ±0.3206	4.2476 ±0.9805	8.6729 ±1.2228
25 Krad	0.3379 ±0.0511	1.3321 ±0.3198	3.3975 ±0.9073	11.2239 ±2.1511
50 Krad	0.2858 ±0.0917	1.3076 ±0.4028	2.9505 ±0.7650	9.3372 ±2.9072
75 Krad	0.2355 ±0.0865	1.4545 ±0.4006	3.2607 ±1.4160	8.1046 ±1.2879
100 Krad	0.2074 ±0.0431	1.1823 ±0.3415	1.9347 ±0.5257	6.8654 ±1.8048
125 Krad	0.1481 ±0.0305	1.0722 ±0.2347	1.6079 ±0.5836	6.1484 ±1.3134
150 Krad	0.1334 ±0.0492	1.0070 ±0.3099	1.4605 ±0.4985	5.7744 ±1.4558

: ± S.E.

Table : 15 Rate of upper-ground biomass production in terms of dry weight (gm) of M_2 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0664 ±0.0110	0.2480 ±0.0540	0.5620 ±0.1483	1.6343 ±0.2588
25 Krad	0.0390 ±0.0170	0.1954 ±0.0521	0.6251 ±0.1666	2.0626 ±0.3910
50 Krad	0.0223 ±0.0086	0.1960 ±0.0678	0.5682 ±0.1361	1.8104 ±0.4896
75 Krad	0.0333 ±0.0114	0.2256 ±0.0501	0.5317 ±0.2413	1.6051 ±0.2848
100 Krad	0.0274 ±0.0083	0.1882 ±0.0552	0.2715 ±0.0714	1.2518 ±0.3123
125 Krad	0.0227 ±0.0053	0.1888 ±0.0386	0.2672 ±0.0888	1.1180 ±0.2500
150 Krad	0.0211 ±0.0054	0.1882 ±0.0324	0.2676 ±0.1112	1.1839 ±0.3408

: ± S.E.

Under-ground biomass - The underground biomass at corresponding stages of plant development has also been calculated in the same manner and has been given in Table 15. The fresh weight analysis of roots revealed that the control plants produced the highest amount of mass and it was closely followed by 25 krad treatment having no statistical difference. The root weight obtained under 50 and 75 krad treatments did not differ from each other and also with the amount produced by 25 krad treatment, but showed a highly significant difference with those of 100, 125 and 150 krad treatments.

At the second stage, the root mass showed a different picture on fresh weight basis. The control being at the top of production stood at a significantly higher level than others. The plants of 25 and 50 krad treatments followed the control but produced significantly less biomass compared to that of control. Among the rest, the 75 krad treatment produced higher biomass than others.

At the next stage of development (45 days), the production of control and 25 krad treatment fall at the same level on analysis; 50 and 75 krad treatments came almost to the same level, while the rest at a lower level with the lowest at 150 krad treatment.

At 60 day old stage, the trend followed the same as in the previous stage.

The dry weight analyses of the root at the corresponding stages of development have revealed at the first stage, the dry weight also followed the same trend as that of the fresh one in having no significant difference between the control and the 25 krad treatment. However, the 50 krad treatment showed a very poor performance at this stage. The root mass produced by the plants under 50 krad treatment happened to be much less than that of 75 and 100 krad treatments (Table 17).

At the next stage of analysis, the 50 krad treatment improved to the level of 25 krad treatment, while 75 and 100 krad treatments demonstrated a poor dry mass production at the underground level. In the next two stages of development that is at 45 and 60 day old stage, the control and 25 krad treatment produced the same amount of root mass. 50 krad treatment produced higher amount than 75 krad treatment at 45 day old stage but not at 60 day old level. 100 krad treatment showed an improvement at sixty day stage to equal the biomass production at the underground level with that of 50 and 75 krad treatments, while the high intensity treatments (125 and 150 krads) showed a consistently poor level of production at all stages of analysis.

The underground biomass in M_2 generation on fresh weight basis at the first stage of observation showed an increase over the first generation under all treatments. The treated plants, however, produced lesser amount of biomass on fresh weight basis

Table : 16 Rate of under-ground biomass production in terms of fresh weight (gm) of M_4 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0900 a ±0.0131	0.1336 a ±0.0236	0.5034 a ±0.1818	0.6730 a ±0.1757
25 Krad	0.0723 ab ±0.0171	0.0786 bc ±0.0139	0.4661 a ±0.0786	0.6598 ab ±0.2973
50 Krad	0.0703 b ±0.0090	0.1028 b ±0.0371	0.2584 b ±0.1460	0.2960 bc ±0.0545
75 Krad	0.0535 b ±0.0125	0.0686 c ±0.0169	0.2088 bc ±0.0747	0.2780 c ±0.0988
100 Krad	0.0339 c ±0.0130	0.0367 d ±0.0036	0.0911 cd ±0.0363	0.1406 cd ±0.0746
125 Krad	0.0292 c ±0.0103	0.0370 d ±0.0087	0.0624 d ±0.0324	0.0672 d ±0.0223
150 Krad	0.0191 c ±0.0028	0.0290 d ±0.0072	0.0401 d ±0.0227	0.0455 d ±0.0122

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 17 Rate of under-ground biomass production in terms of dry weight (gm) of M_1 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0118 a ±0.0011	0.0268 a ±0.0051	0.0862 a ±0.0226	0.2000 a ±0.0394
25 Krad	0.0103 ab ±0.0015	0.0166 bc ±0.0022	0.0789 ab ±0.0129	0.1801 a ±0.0672
50 Krad	0.0081 cd ±0.0006	0.0199 b ±0.0060	0.0678 b ±0.0113	0.0788 b ±0.0349
75 Krad	0.0101 abc ±0.0021	0.0131 cd ±0.0039	0.0403 c ±0.0157	0.0782 b ±0.0108
100 Krad	0.0086 bcd ±0.0030	0.0120 cd ±0.0048	0.0183 d ±0.0112	0.0409 bc ±0.0225
125 Krad	0.0075 d ±0.0010	0.0084 de ±0.0028	0.0146 d ±0.0066	0.0284 c ±0.0046
150 Krad	0.0045 e ±0.0008	0.0049 e ±0.0011	0.0088 d ±0.0046	0.0182 c ±0.0052

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

compared to that of control. At the second stage of observation, the fresh weight produced by treated plants as in the first stage remained lesser than that of control. But among the different treatments, the decreasing trend with the increasing dosage was found to be disturbed in case of 75 krad treatment in which the fresh weight of root system surpassed that of all other treatments. In 45 day old plants, the 25 krad treatment produced the highest underground biomass. The rest of the treatments yielded decreasing amount of root mass with increasing dosage. However, the underground biomass produced by the second generation of plants was found to be higher under all treatments irrespective of the dosage level. The analysis at 60 day old stage also revealed the same trend of results but the fresh mass produced at this stage being remarkably higher compared to the other stages of observation (Table 18).

The underground biomass, when analysed on dry weight basis, it was noticed that the dry weight of treated plants showed a decrease over the control in different degrees depending on the dosage level at all stages of observation (Table 19). A comparison of dry weights of underground biomass, the first and second generations had revealed that the second generation yielded higher mass than the first generation under all treatments. As described earlier, the biomass production of root system on dry weight basis also indicated the recovery rate to be many times higher at higher levels of doses.

Table : 18 Rate of under-ground biomass production in terms of fresh weight (gm) of M_2 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0848 ±0.0091	0.1274 ±0.0119	0.5114 ±0.1294	0.6948 ±0.1911
25 Krad	0.0786 ±0.0088	0.0932 ±0.0156	0.6053 ±0.1192	0.7258 ±0.1355
50 Krad	0.0761 ±0.0141	0.0897 ±0.0140	0.3869 ±0.1603	0.7686 ±0.1116
75 Krad	0.0690 ±0.0101	0.1264 ±0.0109	0.2820 ±0.1036	0.6934 ±0.1720
100 Krad	0.0494 ±0.0084	0.0881 ±0.0119	0.2083 ±0.0642	0.5556 ±0.1013
125 Krad	0.0420 ±0.0068	0.0744 ±0.0127	0.1666 ±0.0530	0.5221 ±0.1069
150 Krad	0.0386 ±0.0087	0.0581 ±0.0125	0.1142 ±0.0202	0.3750 ±0.1084

: ± S.E.

Table : 19 Rate of under-ground biomass production in terms of dry weight (gm) of M_2 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0120 ±0.0013	0.0272 ±0.0043	0.0888 ±0.0206	0.2442 ±0.0573
25 Krad	0.0112 ±0.0019	0.0237 ±0.0055	0.0812 ±0.0143	0.1992 ±0.0580
50 Krad	0.0115 ±0.0016	0.0252 ±0.0051	0.0784 ±0.0176	0.1877 ±0.0404
75 Krad	0.0107 ±0.0017	0.0268 ±0.0057	0.0470 ±0.0137	0.1636 ±0.0731
100 Krad	0.0105 ±0.0011	0.0165 ±0.0046	0.0299 ±0.0117	0.1530 ±0.0720
125 Krad	0.0097 ±0.0018	0.0139 ±0.0041	0.0259 ±0.0083	0.1466 ±0.0363
150 Krad	0.0091 ±0.0026	0.0120 ±0.0027	0.0215 ±0.0128	0.1008 ±0.0612

: ± S.E.

Total biomass - The biomass production of the progenies raised from the treated seeds as well as the control was calculated on the basis of the total fresh and dry weights at fortnightly intervals. The statistical analysis of the results indicate that at the initial stage of seedling growth, the highest biomass was produced by the control plants both on the basis of fresh weight (Table 20) and dry weight (Table 21). A slightly lesser amount (not statistically different) was produced by 25 krad treatment. The progeny of 50 krad treatment also produced a biomass which apparently amounted a little lesser than 25 krad treatment but the statistical analysis had proved the amounts being not varient both at fresh as well as dry weight basis. 75 krad treatment resulted in significantly lesser biomass on fresh weight basis but not on dry weight basis with that of the first two treatments described above. The rest of the treatments of higher intensity doses produced a poor amount of biomass in general.

The analysis of 30 day old seedlings had shown that the control plants to be the maximum producers of biomass. The first three treatments that is 25, 50 and 75 krads produced more or less the same amount of biomass on fresh weight basis which was found to be significantly less compared to that of control. The dry weight analysis of the same had brought to light that the dry mass of 25 and 50 krad treatments being not significantly different from that of control but the 75 krad treatment being

Table : 20 Rate of total biomass production in terms of fresh weight (gm) of M_1 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.6960 a ±0.0948	1.7753 a ±0.3583	5.6274 a ±2.3068	9.3356 a ±3.2663
25 Krad	0.6117 ab ±0.1236	1.3806 b ±0.1566	5.2966 a ±0.7842	9.4822 a ±2.4406
50 Krad	0.5609 b ±0.0993	1.3440 b ±0.3973	4.5715 ab ±0.5624	5.6364 b ±1.8414
75 Krad	0.4380 c ±0.0420	1.0340 b ±0.2073	3.3046 b ±0.9863	5.1018 b ±2.3083
100 Krad	0.3252 d ±0.0238	0.5814 c ±0.1390	1.6745 c ±0.8952	3.7441 bc ±1.6942
125 Krad	0.2948 d ±0.0259	0.6632 c ±0.1704	1.2404 c ±0.3703	1.9048 c ±0.7969
150 Krad	0.2654 d ±0.0303	0.3599 c ±0.0440	1.1777 c ±0.2136	1.3392 c ±0.4035

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 21 Rate of total biomass production in terms of dry weight (gm) of M_1 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0777 a ±0.0124	0.2693 a ±0.0482	0.7969 a ±0.2865	1.9276 a ±0.5949
25 Krad	0.0670 ab ±0.0166	0.2082 ab ±0.0142	0.7382 a ±0.1120	1.9222 a ±0.4404
50 Krad	0.0554 bc ±0.0096	0.2017 abc ±0.0438	0.6874 ab ±0.0662	1.2651 b ±0.4017
75 Krad	0.0623 b ±0.0076	0.1575 bc ±0.0318	0.5086 b ±0.1297	1.1318 bc ±0.3706
100 Krad	0.0455 cd ±0.0090	0.1034 cd ±0.0340	0.2981 c ±0.1536	0.8740 bcd ±0.3483
125 Krad	0.0352 de ±0.0042	0.1141 bcd ±0.0252	0.2226 c ±0.0678	0.6999 cd ±0.2390
150 Krad	0.0237 e ±0.0053	0.0520 d ±0.0105	0.2131 c ±0.0339	0.3915 d ±0.1349

: ± S.E.

: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

significantly less than that of control. As in the first stage of analysis, the last three high intensity treatments resulted in a poor biomass production at 30 day stage.

The 45 day old stage on a similar analysis had revealed that the control plants and the 25 krad treatment produced same amount of biomass at this stage. The 50 krad treatment also produced near about the same amount of fresh weight and dry mass to that of control and 25 krad treatment. 75 krad treatment produced a moderate amount of biomass which on analysis had proved to be not significantly different from that of 50 krad treatment. The rest three treatments repeated the same trend of results as recorded at the previous two stages of plant growth.

The final analysis based on 60 day old plants had proved that there was no difference in biomass production between the control plants and 25 krad progeny, whereas, the 50, 75 and 100 krad treatments gave rise to statistically similar biomass production at this stage. The last two treatments of 125 and 150 krads still lagged behind the others in their biomass production.

Results obtained in the M_2 generation regarding the biomass production of the progenies indicate that the fresh weight (Table 22) as well as the dry weight (Table 23) of the plants under different treatments showed a decreasing trend with the increasing doses of the treatment as in the first

Table : 22 Rate of total biomass production in terms of fresh weight (gm) of M_2 generation of Linum usitatissimum L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.6539 ±0.0591	1.8185 ±0.3205	4.7590 ±0.9469	9.3677 ±1.1334
25 Krad	0.4166 ±0.0545	1.4253 ±0.3317	3.9028 ±1.0041	11.9496 ± 2.1696
50 Krad	0.3620 ±0.1020	1.3973 ±0.3951	3.3374 ±0.6842	10.1058 ± 2.0522
75 Krad	0.3045 ±0.0628	1.5809 ±0.4096	3.5427 ±1.4382	8.8780 ±1.4342
100 Krad	0.2568 ±0.0434	1.2704 ±0.3392	2.1431 ±0.5022	7.4210 ±1.8666
125 Krad	0.1901 ±0.0287	1.1466 ±0.2447	1.7745 ±0.6070	6.6704 ±1.3021
150 Krad	0.1720 ±0.0511	1.0651 ±0.3134	1.5747 ±0.5040	6.1494 ±1.4345

: ± S.E.

Table : 23 Rate of total biomass production in terms of dry weight (gm) of M_2 generation of *Linum usitatissimum* L.

Treatment	Days After Germination			
	15	30	45	60
Control	0.0783 ±0.0117	0.2752 ±0.0535	0.6508 ±0.1347	1.8784 ±0.2223
25 Krad	0.0502 ±0.0151	0.2191 ±0.0541	0.7063 ±0.1748	2.2616 ±0.4017
50 Krad	0.0338 ±0.0088	0.2212 ±0.0641	0.6436 ±0.1465	1.9981 ±0.4611
75 Krad	0.0440 ±0.0106	0.2524 ±0.0465	0.5787 ±0.2392	1.7687 ±0.3178
100 Krad	0.0392 ±0.0083	0.2047 ±0.0534	0.3014 ±0.0753	1.4048 ±0.3635
125 Krad	0.0324 ±0.0043	0.2027 ±0.0416	0.2932 ±0.0969	1.2647 ±0.2545
150 Krad	0.0302 ±0.0059	0.2002 ±0.0303	0.3092 ±0.1169	1.2847 ±0.2936

: ± S.E.

generation. The analysis on 15 day old plants had revealed that the biomass production happened to be lower in the second generation than in the first one, both on fresh and dry weight basis. A similar analysis of 30 day old seedlings had shown that the biomass production happened to be somewhat higher under all treatments compared to that of the M_1 generation. The increase in the biomass rate was found to be higher at the higher dosages than that of the lower ones, indicating that the recovery rate being somewhat higher in the progenies which suffered higher damage in the first generation due to gamma-irradiation.

In the third stage analysis of biomass in 45 day old seedlings there was, however, the trend of result appeared to be somewhat different. In the first two treatments involving 25 and 50 krad intensities, the biomass production declined from that of the first generation to some extent but in the other treatments there had been a sharp rise in biomass production especially at higher levels of gamma-irradiation following the same trend as in the previous stage of 30 day old plants.

The analysis at 60 day old stage, again the biomass production showed a peer trend compared to that of the first generation. There had been a remarkable recovery at this stage of growth in those which experienced the higher doses vis-a-vis high damages in the previous generation (Fig. 3 & 4).

Figure 3: Effect of different acute doses of gamma-rays on the total biomass of *Linum usitatissimum* L. var. nesium in terms of fresh weight.

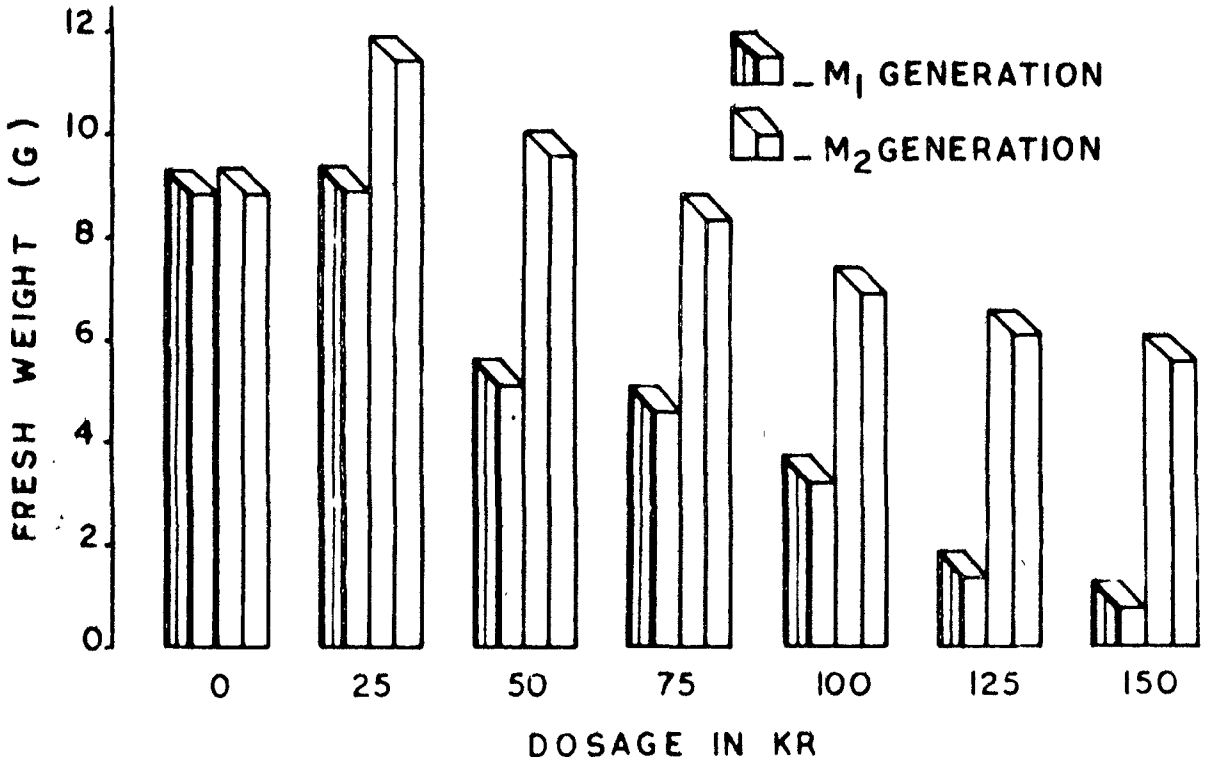

FRESH WEIGHT (G)
12
10
8
6
4
2
0
M1 GENERATION
M2 GENERATION
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 3

Figure 4: Effect of different acute doses of gamma-rays on the total biomass of *Linum usitatissimum* L. var. neelum in terms of dry weight.

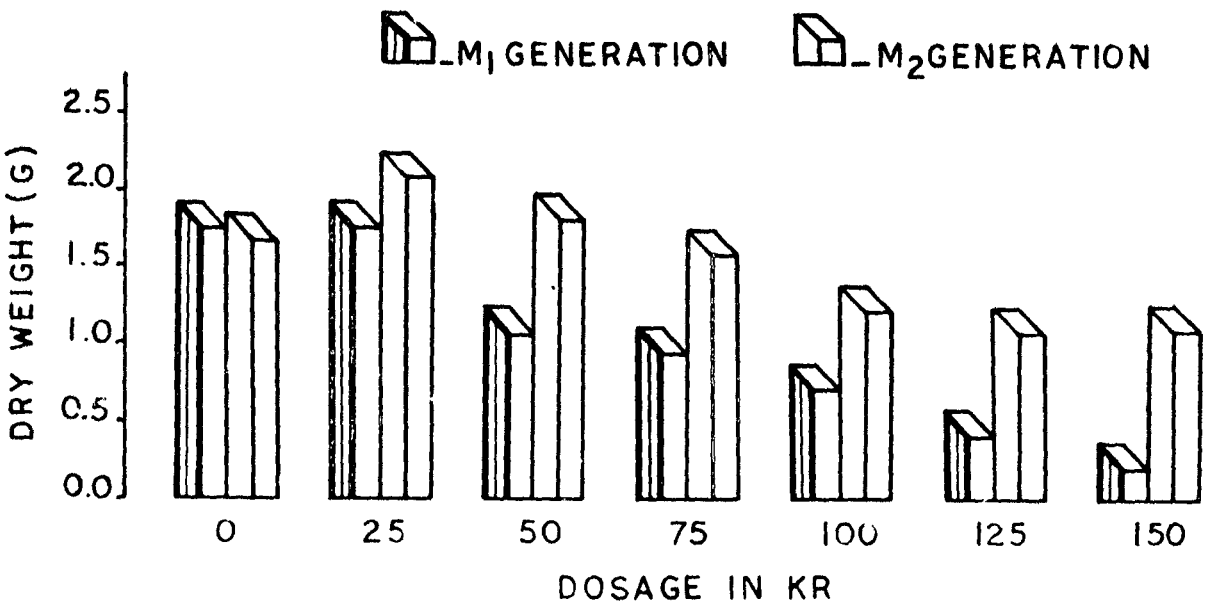

M1 GENERATION
M2 GENERATION
DRY WEIGHT (G)
2.5
2.0
1.5
1.0
0.5
0.0
0
25
50
75
100
125
150
DOSAGE IN KR

FIG.4

floral branches - The floral branches generally developed after eight weeks' duration of vegetative growth in control as well as in lower doses, but in higher doses, the development of such branches had been delayed by two to three weeks, depending on the intensity of irradiation treatment. Contrary to the vegetative phase, the reproductive phase had been noticed to follow at a rapid rate in treated progenies. In all the treatments the number of floral branches exceeded that of control. The increase over the control followed a gradual trend from lower to higher doses (Table 24).

In the second generation the same trend of increase in the number of floral branches per plant over the control had been noticed. However, there was a marked decrease in the number of branches per plant in all doses compared to the M_1 generation except the 25 krad treatment (Table 25).

Capsules - When the number of fruits developed, were analysed it had been found that it decreased per plant in all treatments compared to control (Fig. 5). In higher doses the decrease was highly significant while at the lower doses it remained only marginal (Table 24).

In the second generation the number of fruits per plant increased considerably compared to previous generation, especially in the progenies raised from treatments ranged from 100

to 150 krad intensity. In lower doses, the rise in the number of fruits per plant did not happen to be considerable (Table 25).

Seeds - The control plants yielded 378.43 and 375.66 seeds per plant in the two years of study. The treated progeny showed a marked difference in the output of seeds compared to the control of both the years. In M_1 generation, the 25 krad treatment yielded about 300 seeds per plant. In 100 krad treatment, the seed number was reduced to 83.70 per plant. This was further reduced to 70.88 and 25.76 in 125 and 150 krad treatments respectively. It has become thus obvious that yield per plant is highly affected by the irradiation treatment. The loss in the yield followed proportionately with the intensity of the dosage (Table 24).

In M_2 generation, the yield picture proved to be different from what had been obtained in the first generation. Contrary to M_1 generation, here, one could find a marked increase in yield per plant at least in the case of 25 krad treatment in which the number of seeds per plant exceeded that of control by 15 seeds. In 50 krad treatment the seed output almost equalled the control. In 75 krad treatment it was slightly less than control. In other treatments, although there was a considerable improvement over the previous generation, it remained, however, lower to that of control. On the whole in the second generation the seed output was considerably improved in all cases (Table 25).

Table : 24 Yield per plant in M_1 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Floral Branches No./plant	Capsule No./plant	Seed No./plant	Weight of 1000 seeds/ treatment (gm)
Control	18.92 d ± 0.90	45.44 a ± 1.34	378.43 a ± 31.09	11.5348 b ± 0.2291
25 Krad	21.84 c ± 1.48	43.04 bc ± 1.67	299.69 b ± 37.47	11.8324 ab ± 0.3497
50 Krad	27.60 b ± 1.79	44.64 ab ± 2.00	263.14 c ± 12.13	12.0824 a ± 0.2351
75 Krad	29.72 ab ± 1.69	41.28 c ± 1.45	186.06 d ± 34.93	12.0676 a ± 0.4002
100 Krad	30.68 a ± 2.57	20.72 d ± 2.08	83.70 e ± 14.80	11.8064 ab ± 0.3956
125 Krad	31.90 a ± 1.98	17.16 e ± 1.95	70.88 e ± 15.98	11.7324 ab ± 0.1658
150 Krad	31.56 a ± 1.68	8.84 f ± 1.39	25.76 f ± 5.91	10.7606 c ± 0.5243

: ± S.E.

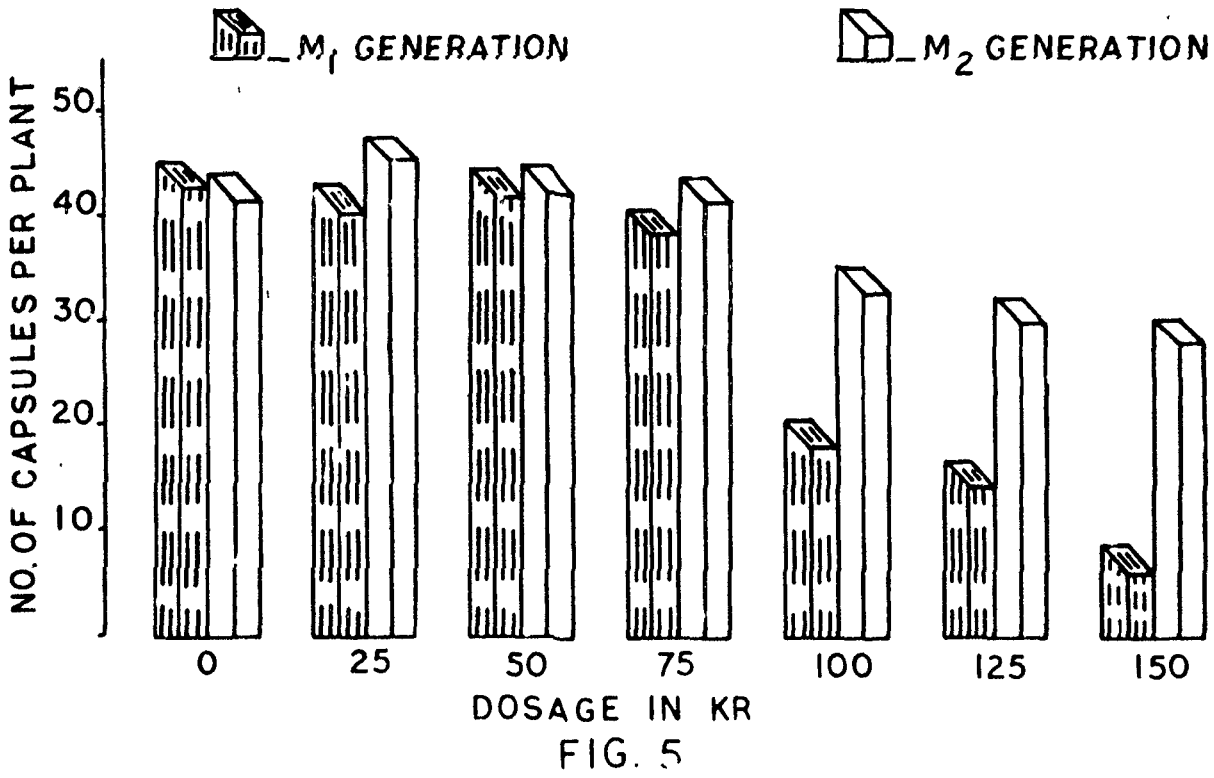
: Means followed by the same letters are not significantly different from each other at the 5% level by Duncan's Multiple Range Test.

Table : 25 Yield per plant in M_2 generation of *Linum usitatissimum* L. under different gamma-ray treatments.

Treatment	Floral Branches No./plant	Capsule No./plant	Seed No./plant	Weight of 1000 seeds/ treatment (gm)
Control	19.20 ± 1.22	44.30 ± 1.40	375.61 ± 23.55	11.3652 ± 0.2088
25 Krad	21.80 ± 2.42	47.92 ± 1.14	391.01 ± 42.04	11.0452 ± 0.1666
50 Krad	22.26 ± 1.80	45.16 ± 1.12	375.31 ± 35.13	11.4504 ± 0.2412
75 Krad	22.82 ± 1.24	44.26 ± 1.89	334.98 ± 39.97	11.2786 ± 0.2782
100 Krad	24.86 ± 2.57	38.38 ± 2.21	260.48 ± 52.56	10.8368 ± 0.7948
125 Krad	19.94 ± 2.24	32.50 ± 3.25	178.85 ± 21.04	11.7288 ± 0.3558
150 Krad	21.36 ± 1.82	30.66 ± 1.87	177.93 ± 40.55	11.2272 ± 0.0930

: ± S.E.

Figure 5: Effect of different acute doses of gamma-rays on fruit set of *Linum usitatissimum* L. var. neelum.


M1 GENERATION
M2 GENERATION
NO. OF CAPSULES PER PLANT
50
40
30
20
10
0
25
50
75
100
125
150
DOSAGE IN KR
FIG. 5

Fresh weight of 1000 seeds - 1000 seeds of control plants weighed 11.5348 grams, whereas a similar number of seeds in 25 krad treatment weighed 11.8324 grams. In 50 and 75 krad treatments the seed weight improved further. In 100 and 125 krad treatments also the seed weight showed an increase but in 150 krad treatment their weight fell by 0.7742 grams per 1000 seeds (Table 24).

In M_2 generation, the seed weight stabilished in all cases irrespective of their irradiation history. The weight of 1000 seeds ranged from 11.0452 to 11.7288 in the treated individuals, the lowest being in the 25 krad treatment and the highest in 125 krad treatment (Table 25). The decrease or the increase of the seed weight of the second generation compared to the first one has been depicted in the figure 6.

Moisture content of the seeds - The moisture content of the seeds was calculated by weighing the seeds before and after drying in oven until a constant dry weight was obtained. The difference in the fresh and dry weight was taken as the amount of water, the seeds had conserved. The moisture content of the seeds of control was determined only once from the seeds of M_1 generation and the performance of the seeds of different treatments in M_2 generation was, however, also compared with the control of the previous generation.

Figure 6: Effect of different acute doses of gamma-rays on the weight of seeds of *Linum usitatissimum* L. var. neelum.

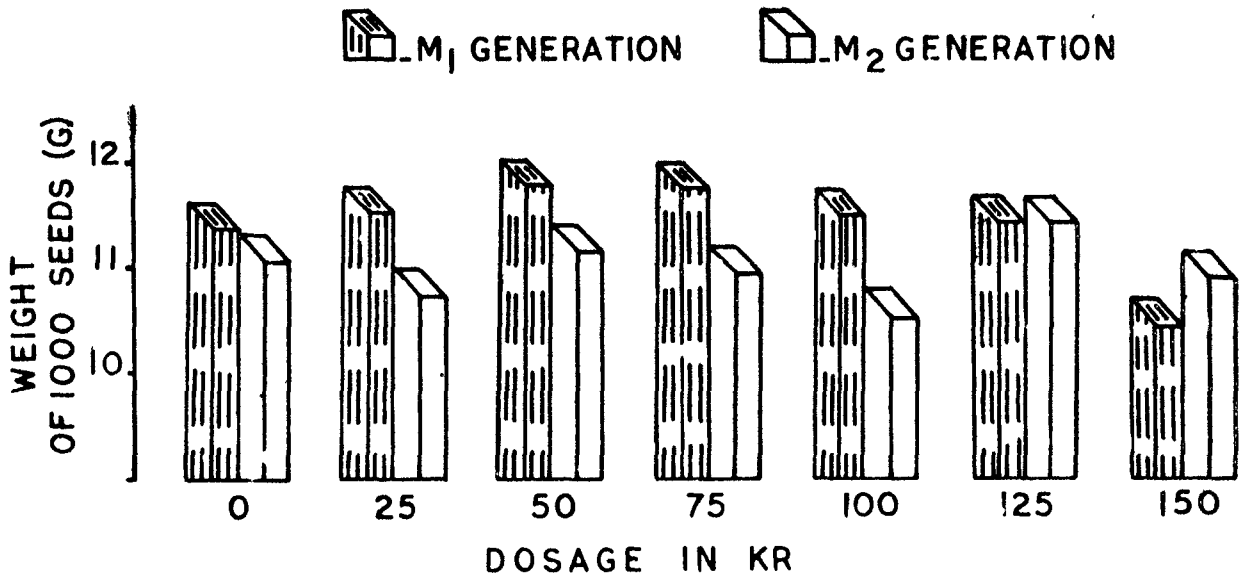

M1 GENERATION
M2 GENERATION
WEIGHT OF 1000 SEEDS (G)
12
11
10
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 6

When the seeds of the different treated progenies in M_1 generation were analysed to know about their water holding capacity, it was found that the treated seeds held more water in comparison to control, except the 150 krad treatment. The 50 krad treatment enriched the seeds with highest amount of water and this was followed by 75, 100, 25 and 125 krad treatments (Table 26).

The seeds of the different treatments in M_2 generation held slightly lesser amount of water in comparison to M_1 generation. There was no marked difference in the water holding capacity of the control and of the different treatments except the 150 krad treatment in which only 4.00% moisture was recorded (Table 27).

Oil and fatty acid contents - The oil content of the seeds was calculated by extraction method described under the chapter II. The oil content and fatty acid composition of the seeds of control was worked out only once from the seeds of control obtained in M_1 generation. In M_1 generation, the control seeds yielded the highest amount of oil. Among the treated ones, the lowest oil yield was recorded under 75 krad treatment while the highest under 25 krad treatment. The second highest of oil yield was obtained under 150 krad treatment. The seeds of 50, 100 and 125 krad treatments yielded 30.20, 29.17 and 29.18% oil respectively (Table 26).

The treated seeds of M_2 generation showed considerable recovery in their oil yield at all the levels of irradiation treatment. The seeds of 150 and 25 krad treatment yielded more oil in comparison to control (Table 27).

When the different fatty acid composition was analysed, it was found that gamma radiation changed the relative composition of the saturated and unsaturated fatty acids (Fig. 7 & 8). Linolenic acid was found to be a major content of the fatty acids in linseed oil. It was found to be highest in seeds obtained from 75 krad treatment. This was closely followed by 125 krad treatment. The 25 and 100 krad treatments yielded almost in equal amount of linolenic acid in seeds. This fatty acid amounted at a higher level in the treated seeds in general compared to control except in 150 krad treatment (Table 26). In M_2 generation, however, the treated seeds showed higher amount of this fatty acid at all the levels of irradiation (Table 27).

The highest amount of Linoleic acid was found under the treatment of 50 krad intensity. The next highest amount was recorded in 25 krad treatment which was followed by 75, 100 and 125 krad treatments. As in the previous case, here also the control seeds contained lesser amount of Linoleic acid than the treated ones excepting that of 150 krad treatment in M_1 generation. In M_2 generation, however, the first four treatments yielded higher amount of Linoleic acid in comparison to control. Oleic acid content was found to be higher in control as well as

Table : 26 Seed quality in terms of moisture and oil contents, fatty acid composition and iodine value in M_4 generation of Linum usitatissimum L. under different gamma-ray treatments.

Treatment	Moisture content of seeds %	Oil content of seeds %	Fatty acid composition (wt. %)					Iodine value (G.L.C.)
			Saturated		Unsaturated			
			Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	
Control	6.05	33.14	12.50	4.80	26.00	14.60	41.90	163.17
25 Krad	6.66	30.71	9.24	6.43	16.67	19.87	47.79	179.80
50 Krad	7.48	30.20	11.37	5.33	17.76	22.20	43.34	172.90
75 Krad	7.13	28.80	15.09	3.23	9.43	18.88	53.37	204.60
100 Krad	6.80	29.17	10.90	2.62	21.60	17.30	47.58	179.04
125 Krad	6.65	29.68	10.80	3.90	16.60	16.60	52.10	185.50
150 Krad	5.61	30.34	8.30	2.60	35.50	13.10	40.50	164.90

Table : 27 Seed quality in terms of moisture and oil contents, fatty acid composition and iodine value in M_2 generation of Linum usitatissimum L. under different gamma-ray treatments.

Treatment	Moisture content of seeds %	Oil content of seeds %	Fatty acid composition (wt. %)					Iodine value (G.L.C.)
			Saturated		Unsaturated			
			Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3	
Control	6.05	33.14	12.50	4.80	26.00	14.80	41.90	163.17
25 Krad	5.99	33.68	6.80	7.10	17.90	16.20	52.00	185.70
50 Krad	6.35	32.79	8.80	5.10	19.30	17.30	49.50	182.20
75 Krad	5.34	31.88	10.40	5.50	15.50	15.50	53.10	185.20
100 Krad	5.77	30.39	6.10	3.50	14.30	17.40	58.70	202.60
125 Krad	6.63	31.86	7.60	5.00	17.50	13.10	56.80	192.70
150 Krad	4.00	34.30	7.80	4.00	19.30	14.40	54.50	190.40

Figure 7: Effect of different acute doses of gamma-rays on fatty acids composition of the oil content of *Linum usitatissimum* L. var. neelum in M_1 generation.

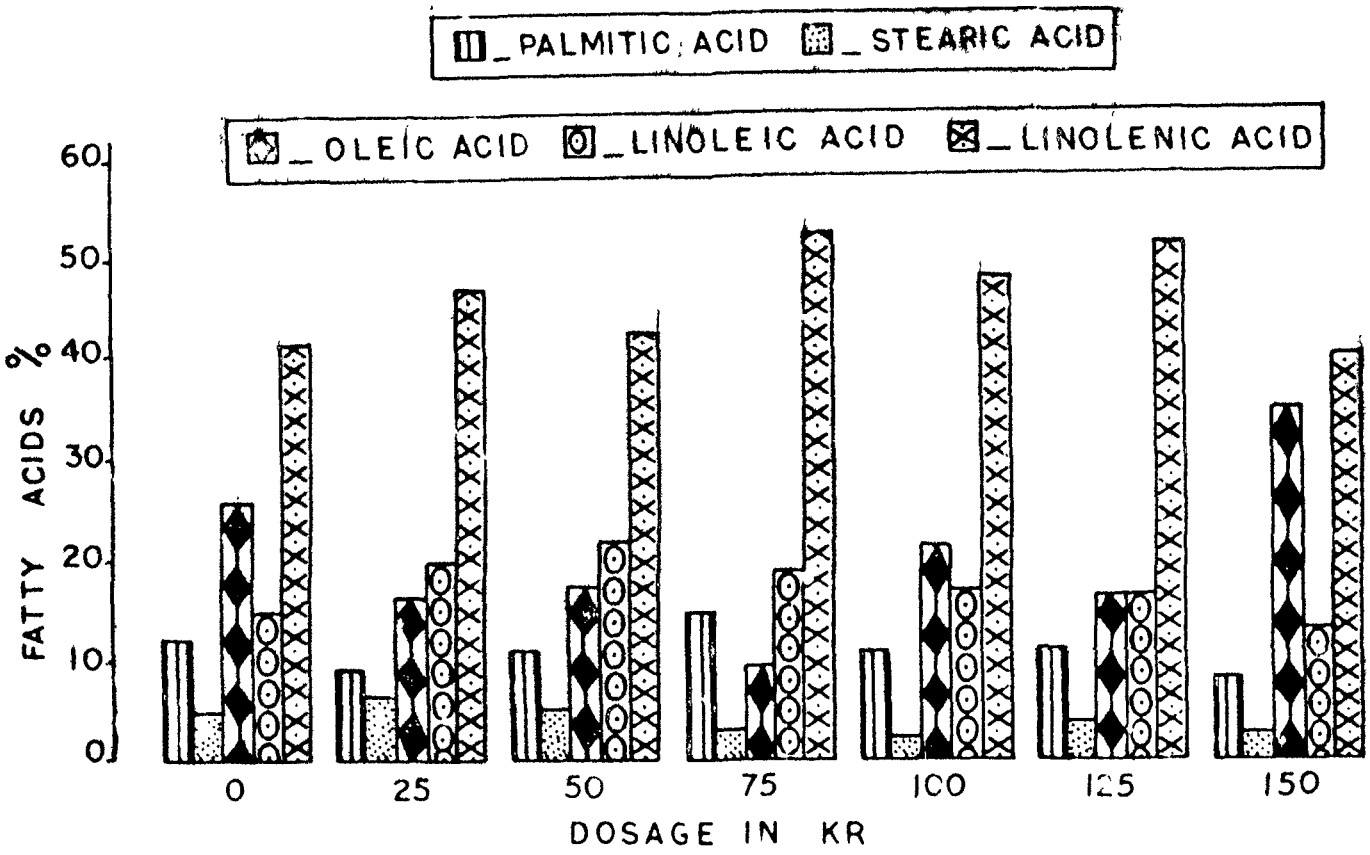

PALMITIC ACID
STEARIC ACID
OLEIC ACID
LINOLEIC ACID
LINOLENIC ACID
FATTY ACIDS %
60
50
40
30
20
10
0
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 7

Figure 8: Effect of different acute doses of gamma-rays on fatty acids composition of the oil content of *Linum usitatissimum* L. var. neelum in M_2 generation.

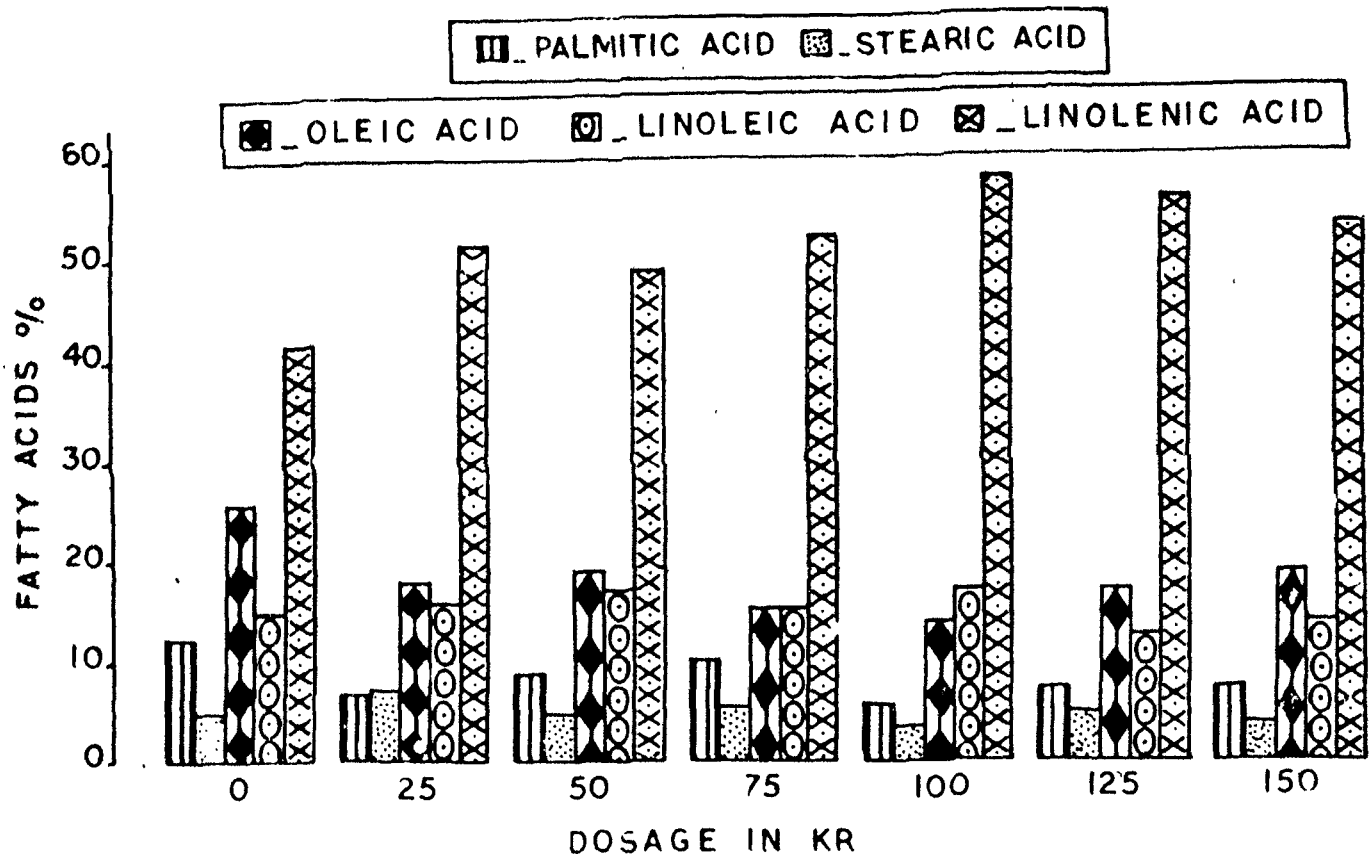

PALMITIC ACID
STEARIC ACID
OLEIC ACID
LINOLEIC ACID
LINOLENIC ACID
FATTY ACIDS %
60
50
40
30
20
10
0
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 8

in 150 krad treatment compared to seeds obtained from other treatments. In general, the Oleic acid content of the seeds appeared to be highly affected by the irradiation treatment excepting the highest dosage. The Oleic acid content of the treated seeds in M_2 generation was found to be less than control at all the levels of irradiation.

Stearic acid was found to be highest in 25 krad treatment and this was followed by 50 krad treatment. Under these two treatments, Stearic acid content of the seeds happened to be higher in level than the control, while in the rest of the cases it was found to be less than control. However, in M_2 generation it showed higher values in all the treatments in comparison to control except 100 and 150 krad treatments.

Palmatic acid was found to be higher in control seeds except 75 krad treatment of M_1 generation. The treated seeds showed lesser value of Iodine than the control in both the generations. However, it was found to be highest in 75 krad treatment of M_1 generation.

Variations :

The variations caused by gamma-ray treatments in M_1 generation was studied using the different morphological, anatomical and floral characters including the habit of the plants as parameters.

Habit and morphology - Plants of control and 25 krad treatment showed erect habit, while the plants of 50 krad treatment and those of remaining higher doses showed erect as well as lodged and semi-lodged habits. The percentage of lodged and semi-lodged plants increased with the increasing dosage of gamma-rays. In 50 krad treatment, the semi-lodged and lodged individuals were found to be 8.51 and 2.13 percent respectively. In 75, 100, 125 and 150 krad treatments, the percentage of semi-lodged plants rose to 12.93, 16.63, 26.93 and 19.51 and that of lodged ones to 4.31, 14.41, 21.08 and 30.49 respectively (Table 28).

The shoot apices showed various morphological modifications, especially under high intensity treatments. Among the abnormalities noted, condensation of shoot-apex (Plate IV-E, Plate V-E), conversion of the apex into leaf-like (Plate IV-A) or needle-like (Plate VI-B) bodies and getting twisted (Plate IV-B) or taking curvature (Plate IV-C) were happened to be the common ones.

The phenomenon of stem-bifurcation (Plate V-C, Plate VI-A) was not observed in control, 25 and 50 krad treatments. 10.78 percent plants showed stem-bifurcation in 75 krad treatment, while the same was recorded as 7.76, 14.05 and 12.20 percent in 100, 125 and 150 krad plants respectively (Table 28).

The foliage leaves developed various kinds of abnormalities under the different treatments (Plate V-D). No such abnormality was found in control plants except the fusion of two leaves that too of rare occurrence (Table 28).

Table : 28 Habit and morphology of plants in M_1 generation of *Linum usitatissimum* L. under different gamma-ray treatments. (Percentage).

Treatment	Habit			Morphology			
	Erect	Semi-Lodged	Lodged	Bifurcation		Variegation	Fasciation
				Stem	Leaf		
Control	100.00	-	-	-	1.12	-	-
25 Krad	100.00	-	-	-	3.96	-	-
50 Krad	89.36	8.51	2.13	-	11.67	1.06	-
75 Krad	82.76	12.93	4.31	10.78	14.73	-	1.08
100 Krad	68.96	16.63	14.41	7.76	23.79	-	1.11
125 Krad	51.99	26.93	21.08	14.06	23.64	5.85	2.34
150 Krad	50.00	19.51	30.49	12.20	21.79	3.66	2.44

The percentage of plants showing variegated seedlings in 50 krad treatment was found to be 1.06, while in 125 and 150 krad treatments 5.85 and 3.66 percent respectively (Table 28). However, no variegated plant was obtained under other treatments. Plates V-A, B shows the variegated seedlings under 100 and 150 krad treatments respectively.

The phenomenon of fasciation was not observed in control as well as in the first two lower dosages that is 25 and 50 krad treatments. However, the higher dosages produced fasciated plants (Plate IV-C, Plate V-C) in varying degrees depending on the intensity of dosage (Table 28).

In M_2 generation no such morphological abnormalities and change of habit were noted, although the seeds collected from the effected individuals were sown separately.

Floral variation - A quantitative analysis on the different floral parts was conducted to visualize the variation caused by irradiation treatment. The following variations had been observed.

The size of pedicel when measured in control and in the treated ones had shown that they were shorter in the treated progenies than in the control, the decrease being gradual with increasing dosage (Table 29). However, it showed considerable recovery in M_2 generation (Table 30).

The flowers developed on fasciated branches, especially on the flattened stems and on curved and condensed ones. The inflorescences were being highly condensed gave an appearence of verticillate or head like structures, and the flowers showed a partial or fully fused condition. In such a group of closely packed bunch of flowers, the identity of individual flowers was lost and appeared quite interesting. Such cases of fusion of flowers in fasciated stems were come across in almost all cases of high intensity doses. One of such abnormal condensation of flowers was obtained in 75 krad treatment of M_1 generation (Plate VI-C).

The seeds collected from such abnormal parts of plants did not give rise to the same condition in the second generation, although the seeds germinated and developed into fullfledged individuals.

The number of sepals varied from 5 to 7 in the variety studied, although the flowers of Linum usitatissimum has been described as pentamerous. This variation in the number of sepals had been observed in all cases including the control. However, the occurrence of such abnormal number was found to be more frequent in the treated progeny than in the control.

The length and width of calyx lobes showed a gradual decline from the control to the treated ones in a decreasing order with the increasing dosage (Table 29). This gradual course of decline was interrupted at 50 krad treatment in which the

length of the sepals showed marginal increase over the control. It showed considerable recovery in M_2 generation (Table 30).

In the treated progenies of M_1 generation, it was often observed that the sepals remained stunted and developed highly glabrous nature. They were also found extra ordinarily thick and they did not fully open and as a result, the inner corolla lobes also get packed up. In such cases, the flowers remained half opened with the struggling style just peeping through the partially open flowers. No fruit was observed to develop out of such flowers. Quite often it was also noticed such stunted flowers prematurely dry and drop.

The number of petals was also noticed to vary to a odd number differing from that of normal in all cases of treatments as well as the control. Here also the abnormality was found to be more frequent in treated progenies than in the control. Some times the petals were found to fuse with adjacent ones to show a semi-sympatelous nature. At the same time the petals were found to forks giving an appearance of having developed more number of petaloid members in a flower. Among the abnormalities observed, one or two petals in a flower showed abnormally bigger size than the normal ones. The colour variance from blue to light blue or whitish blue had also been observed in the treated progenies in general. In one interesting case of 100 krad treatment, the flowers developed on the leader shoot were all found to be lightly coloured and smaller in size. In the same plant

these flowers which developed on tillers were normal in colour and size (Plate I-C). Plate I-D shows the normal and reduced flowers as mentioned above in two different individuals under the same treatment of 100 krads. Since these abnormalities did not occur in any recognizable order they were not analysed quantitatively. Such irregularities had been observed in all the treated forms especially in the higher doses but with out showing any regular relation with intensity of the dosage.

The petals showed, as the sepals, a decreasing trend of size variation with the increasing intensity of dosage employed in the treatment with the ratio being higher in the treated ones compared to control (Table 29). The petals also showed recovery in M_2 generation (Table 30).

The measurement of carpels and the stylar portion of the carpels showed that they also followed the same trend as that of the other floral parts in a flower in having smaller dimension in the treated individuals of M_1 generation compared to control and showed recovery in M_2 generation.

Pollen viability - Ninety eight to hundred percent pollen of the control plants responded positively to acetocarmine test, while the pollen of treated progenies responded to a similar test in different degrees depending on the intensity of gamma-rays employed in the treatment. The figure 9 shows the position of pollen-fertility under the different treatments. The effect of

Table : 29 Floral variance (Based on 20 flowers per replicate) induced by gamma-ray treatment in *Linum usitatissimum* L. in M_1 generation.

Treatment	Pedicel Length (cm)	Calyx		Corolla		Gynoecium	
		Length (cm)	Width (cm)	Length (cm)	Width (cm)	Carpel Length (cm)	Style Length (cm)
Control	1.95	0.91	0.41	1.62	1.55	1.00	0.55
25 Krad	1.64	0.89	0.38	1.60	1.47	0.93	0.52
50 Krad	1.59	0.93	0.39	1.43	1.21	0.91	0.48
75 Krad	1.50	0.86	0.37	1.38	1.14	0.91	0.49
100 Krad	1.39	0.86	0.36	1.35	1.21	0.81	0.45
125 Krad	1.10	0.82	0.35	1.31	1.12	0.85	0.44
150 Krad	1.16	0.81	0.35	1.25	1.04	0.77	0.42

Table : 30 Floral variance (Based on 20 flowers per replicate) induced by gamma-ray treatment in *Linum usitatissimum* L. in M_2 generation.

Treatment	Pedicel Length (cm)	Calyx		Corolla		Gynoecium	
		Length (cm)	Width (cm)	Length (cm)	Width (cm)	Carpel Length (cm)	Style Length (cm)
Control	1.94	0.90	0.41	1.60	1.50	1.00	0.65
25 Krad	1.78	0.90	0.41	1.39	1.34	0.88	0.49
50 Krad	1.69	0.95	0.41	1.42	1.40	0.92	0.52
75 Krad	1.80	0.93	0.43	1.48	1.46	0.92	0.50
100 Krad	1.46	0.89	0.36	1.42	1.26	0.90	0.50
125 Krad	1.45	0.88	0.34	1.40	1.22	0.89	0.49
150 Krad	1.42	0.82	0.33	1.40	1.20	0.88	0.49

irradiation happens to be so acute that even in the lowest level of dosage, the fertility has fallen to 58 percent (Table 31). The fertility fell to the minimum of a mere 8 percent in 150 krad treatment.

The M_2 progenies of all the treatments showed a high percentage of fertile pollen comparable to that of control, irrespective of the level of irradiation their mother stocks have experienced except the higher doses of 125 and 150 krad treatments in which about 5 to 7 percent of pollen still remained non-viable in the second generation (Fig. 9).

Anatomical variation - Quantitative analysis of vessels and wood fibres of the different treatments and the untreated control had revealed that the irradiation had caused serious damage in the M_1 generation by reducing the length and width of the tracheary elements. In control, the length average of vessels and fibres measured about 366 and 416 µm respectively, while the width of vessels came about 32 µm in average (Table 32). In contrast to the above the length average in the treated progenies varied from 230 to 336 µm and 266 to 395 µm in vessels and fibres respectively, the reduction showing a linear relationship with the amount of gamma rays employed in the treatment. Similarly, the diameter of vessels also showed a decreasing trend with the increasing intensity of gamma-rays.

The quantitative analysis of vessels and fibres of M_2

Table : 31 Percentage of pollen - viability in M_1 and M_2 generations of Linum usitatissimum L. under different gamma-ray treatments.

Treatment	M_1	M_2
Control	97.78	98.43
25 krad	57.92	97.76
50 krad	25.59	98.46
75 krad	20.74	96.18
100 krad	12.57	95.20
125 krad	10.52	92.96
150 krad	7.83	90.60

Table : 32 Comparative data on vessels and fibres of M_1 and M_2 generations of *Linum usitatissimum* L. treated with different doses of gamma irradiation.

Treatment		Vessels			Fibres	
		Length (µm)	Decrease percent	Width (µm)	Length (µm)	Decrease percent
Control		366	-	32	416	-
25 Krad	M_1	336	8	28	395	5
	M_2	352	4	32	400	4
50 Krad	M_1	329	10	28	365	12
	M_2	351	5	33	389	6
75 Krad	M_1	295	19	27	351	15
	M_2	324	11	36	364	13
100 Krad	M_1	292	20	26	329	21
	M_2	317	13	34	353	15
125 Krad	M_1	266	27	24	315	24
	M_2	289	21	34	350	16
150 Krad	M_1	230	37	23	266	36
	M_2	288	21	34	310	25

generation had revealed that the treated progenies have made - up to a considerable extent the damage caused by gamma-rays in the M_1 generation. Compared to the M_1 generation, the M_2 generation showed the damage to a lesser extent (Fig. 10). The reduction in length of vessels and fibres had been reduced to 21 percent from that of 37 percent in case of vessels and to 25 percent from that of 36 percent in case of fibres under 150 krad treatment. The extent of recovery, therefore, showed an increasing trend with the increasing intensity of gamma rays. The width of vessels, on the other hand, had shown an increase under all treatments, irrespective of the dosage it happened to be higher than that of control. This increase in width of vessels in M_2 plants appears to have been developed to meet the water requirements of the plants when the length of the elements remained still under the stress of gamma-rays.

Figure 9: Effect of different acute doses of gamma-rays on the viability of pollen-grains of *Linum usitatissimum* L. var. neelum.

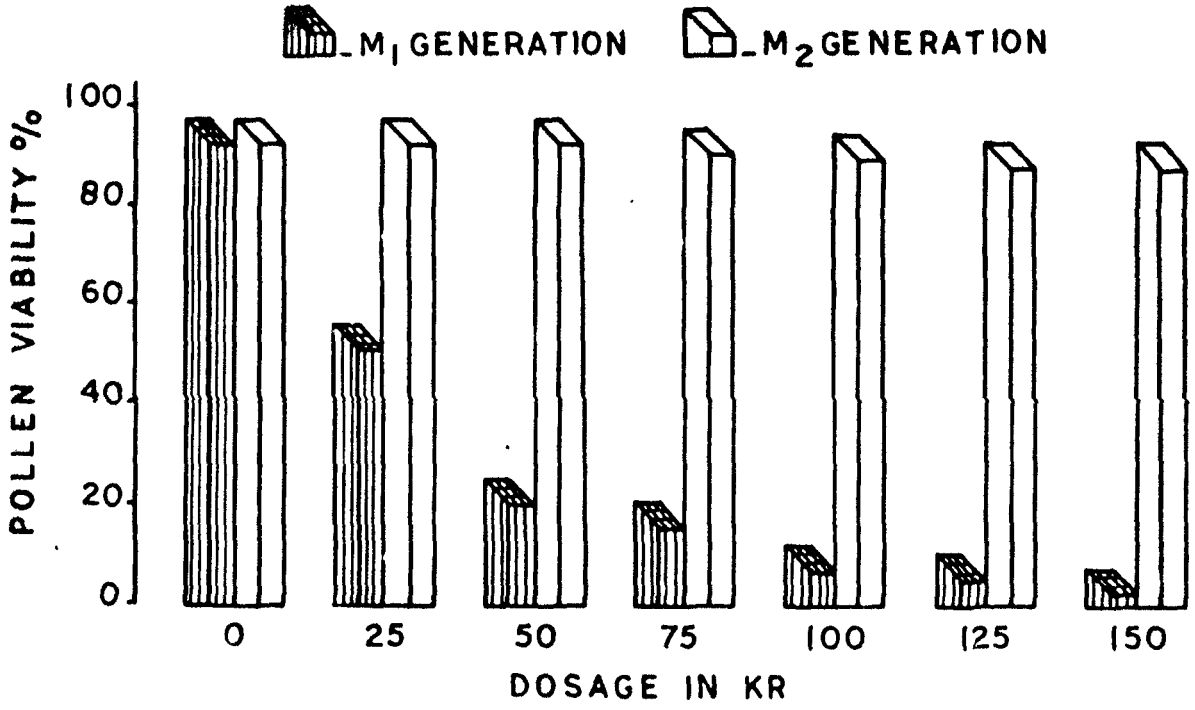

M1 GENERATION
M2 GENERATION
POLLEN VIABILITY %
100
80
60
40
20
0
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 9

Figure 10: Percentage reduction in the length of vessels and fibres of secondary xylem of *Linum usitatissimum* L. var. neelum under the influence of different acute doses of gamma-rays.

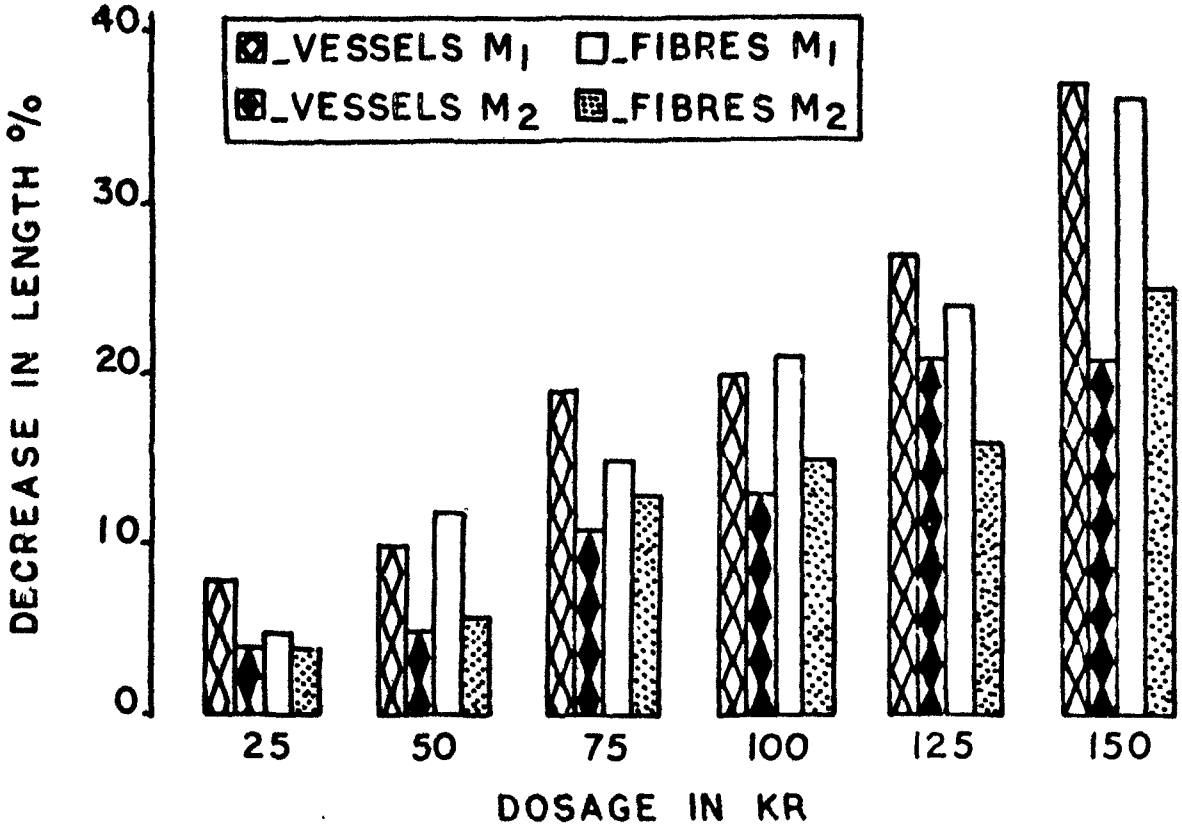

VESSELS M1
FIBRES M1
VESSELS M2
FIBRES M2
DECREASE IN LENGTH %
40
30
20
10
0
25
50
75
100
125
150
DOSAGE IN KR

FIG. 10

D I S C U S S I O N

DISCUSSION

Seed germination :

Effect of X- and gamma-rays on seed germination in higher plants have been studied by several workers such as Johnson (1928), May and Posey (1958), Gustafsson and Simak (1958), Heaslip (1959), Bowen and Thick (1961), Saric et al. (1961), Harring et al. (1964), Morgen and Johansen (1964), Sen and Ghosh (1968), Chauhan (1969), Rai (1971), Chopra (1972), Nath (1974), Raghuvanshi and Singh (1977) and Chaghtai and Siva Prasad (1979). Bowen and Thick (1961), Saric et al. (1961), Preobrazhenskaya and Timofeev - Resovskii (1962), Amer and Hakeem (1964) and Rajan (1969) have found the irradiation treatment to be beneficial, especially at lighter levels, to the process of seed germination in the species investigated by them. However a number of others have found that the heavy doses of gamma-rays destroy the viability of seeds and thus prove lethal to the process (Sen, 1964; Patel and Shah, 1974). In the present study it has been found that the gamma-ray treatments in their light doses do not materially affect the germination percentage of the Indian variety of linseed investigated, but it does adversely affect the same at their heavy doses. Chopra and Singh (1978) in Guizotia abyssinica and Grover and Dhanju (1979) in Papaver rhoeas have also reported decreased seed

germination as a result of gamma-irradiation. However, Brock and Andrew (1965) and Kumar and Das (1978) have not observed any significant effect of gamma-irradiation treatment on seed germination in Medicago polymorpha and Brassica campestris respectively.

No stimulatory effect of gamma-rays, even in the lowest level, has been observed in the present study, as has been reported by Amer and Hakeem (1964) in Lupinus termis, Rajan (1969) in Sesamum indicum, Spiegel-Roy and Padova (1973) in Citrus sinensis, Srivastava et al. (1976) in Soybean, Maltseva (1977) in tomato and Sharon and Muralidharan (1978) in Sorghum. However, Sax (1963) is of the opinion that the stimulatory effects, sometimes exhibiting themselves under low intensity treatments, are of minor magnitude and they are often not reproduceable, although in individual tests the differences may be of some significance.

The delay in germination as well as the slow rate of germination observed in the present study also indicate the adverse role of gamma-rays on the process of germination. A similar observation has also been made by Sen and Ghosh (1968) in Corchorus species, Bajaj et al. (1970) in Phaseolus vulgaris and Patel and Shah (1974) in Solanum melongena and Capsicum annuum. The failure to get the same degree of inhibition and delay in the M_2 generation, as has been noted in the first generation, clearly makes out a case for the physiological disturbance than any genetic change that has been induced by irradiation treatment. Ananthaswamy et al. (1971) are also of the opinion that

the metabolic disturbances occurring during germination due to gamma-irradiation, be responsible for the inhibition of seed germination in wheat.

Decrease in seedling survival as an after effect of irradiation has been reported by Caldecot (1955), Rai (1971), Bari (1971), Chopra (1972) and Raghuvanshi and Singh (1977). In the present study also the plant survival percentage has been found to decrease with increasing dosage of gamma-rays in M_1 generation. However, in M_2 generation, there happens to be no difference in plant survival percentage of control and of the different treatments.

Growth :

The growth in relation to ionizing radiations has been studied in a wide variety of higher plants (Johnson, 1926, 1928, 1931, 1933, 1936a, b, 1939, 1948; Gustafsson, 1944; Levan, 1944; Gunckel and Sparrow, 1954; Sparrow and Gunckel, 1956; Gordon, 1957; Smith, 1958; Sax, 1963; Davies, 1968; Chauhan, 1969; Bari, 1971; Chopra, 1972; Nath, 1974; Sinha and Sinha, 1977; Sharon and Muralidharan, 1978). General growth inhibition by ionizing radiations has been reported in plants by a number of workers (Gunckel and Sparrow, 1961; Dumanovic and Ehrenberg, 1965; Taylor, 1968; Davies, 1968; Chauhan, 1969; Rai, 1971; Chopra, 1972; Nath, 1974; Sharon and Muralidharan, 1978). Johnson (1936c) holds the opinion

that injury and growth are the most common effects following X-ray treatments. While summing up the earlier conflicting views on 'stimulation' or 'reduction' of growth, she has pointed out that a majority of workers have reported that light doses do not cause an increased development of vegetative parts, while medium and heavy doses prove to be injurious. Saric et al. (1961) have observed in wheat seedlings that certain gamma-ray doses are stimulatory while others inhibitory. Over 110 species of plants have been investigated for tolerance levels (Sparrow, 1955; Sparrow and Gunckel, 1956) and most of them show a general decrease in plant height with increase in dosage level. The present study also proves the same for linseed crop. The high intensity doses like 100 krad and above have been found to affect adversely the height of the plant, root length, number of branches and leaves at all stages of growth; the degree of decrease being directly proportional to the exposure dose. It has also been found that the inhibition of the plant growth is more pronounced in M_1 generation in comparison to M_2 generation.

Different workers hold different opinion regarding the phenomenon of stunted growth resulting from irradiation. Important suggestions are: (1) uneven damage to meristematic cells due to genetic injuries (Gray and Scholes, 1951; Lea,

1955), (2) chromosomal damages or inhibition of cell division (Thoday, 1951; Sparrow et al., 1961; Conger and Stevenson, 1969), (3) marked decrease in the auxin level following irradiation (Skoog, 1935; Smith and Kersten, 1942; Gordon, 1954), (4) marked effect on auxin synthesis (Gunckel and Sparrow, 1961) and (5) effect on respiratory enzymes (Bjornseth et al., 1957). Quastler et al. (1952) are of the opinion that irradiation effects on mitosis and the physiological disorders are responsible for stunted growth.

The occurrence of growth stimulation due to irradiation has been observed in a number of cases (Johnson, 1948; Sparrow and Christensen, 1953; Sax, 1955, 1963; Davies, 1968, 1970; Bari, 1971; Malteeva, 1978). Sparrow and Christensen (1953) and Gunckel and Sparrow (1954) have found stimulation of growth of Antirrhinum when subjected to moderate exposures of chronic gamma irradiation. Sparrow and Gunckel (1956) have noticed an increase in plant height in Antirrhinum majus at exposure rates above 125 R/day. Ehrenberg et al.(1954) have observed growth stimulation in Vicia faba at daily exposure range of 16-28 R of gamma-radiation. Donini et al. (1964) have found increased vegetative growth in durum and bread wheats at the daily exposures of 72 and 148 R of gamma-irradiation. De Nettancourt and Contant (1966) have seen a marked increase in plant height of

Lycopersicum species under continuous radiation exposures. Bostract and Sparrow (1970) have also observed a significant increase in tree height at exposure rates of 1-2 R/day in Pinus strobus. While studying the effect of chronic gamma-irradiation, Mikaelsen and Aastveit (1957) have observed considerable increase in plant height at exposures ranging from 25 to 34 R/day in Oats, and from 36 to 45 R/day in barley.

The lower dosages upto the extent of 75 krad have been found to stimulate the height of the plant at maturity in both the generations in the present study. D'Amato (1957) in his studies on the effect of chronic gamma-irradiation in flax, has not been able to find any growth stimulation except in the early stages of plant growth at 375 and 425 R/day. Sari (1971) has found in acute irradiation studies on flax that the plant height at maturity decreases with increasing exposures. While, on the other hand, in the chronically exposed plants of flax, he has noticed that plant height at maturity increases gradually as the daily exposure rate increases from 100 R to 600 R, there after there is a sharp decline, and at 1000 R, the plant height is so much reduced that it measures less than that of the non-irradiated plants.

It has been found in the present investigation that the length of hypocotyl of the treated progenies of M_1 and M_2 generations, shows a decreasing trend with increasing doses of gamma-rays, the decrease being significant at all levels of irradiation. However, a good deal of recovery occurring in the M_2 generation at all levels of irradiation and a slight stimulation over control under 50 and 75 krad treatments have also been found.

Information on the effects of ionizing radiations on cotyledonary expansion is very meagre. Rudolph and Nikache (1970) have observed various degrees of radiosensitivity in the cotyledonary expansion in nine species of Pinus. During the present investigation it has been found that cotyledonary expansion does not get materially affected by gamma-ray treatments, although an apparent stimulation at lighter doses and retardation at heavy doses like 100 and 125 krads do occur in the treated progenies. Chauhan (1969) and Chopra (1972), on the other hand, have found that the cotyledonary expansion undergo in an inversely proportional magnitude with the dosage in Carthamus tinctorius and Guizotia abyssinica respectively.

It has been further found during the present investigation that the fresh and dry weight ratios of the cotyledons of treated plants show a slightly higher value in comparison to control indicating that the cotyledons of treated seedlings

develop a temporary phase of water holding quality after gamma-ray treatment. This newly developed trait of water retention capacity has been further found to be unstable as it disappears in the M_2 generation, when the seedlings recover from the shock of gamma-rays that they received in the previous generation.

In the present investigation, the total fresh and dry weights of the treated seedlings as well as their ratios, have been found to show a significant reduction at higher doses. This decrease in fresh and dry weights of the individuals at higher dosages occur due to decrease in height, number of vegetative branches and number of leaves. Nath (1974) has observed a significant decrease in dry weight of seedlings of Sesamum indicum in the doses higher than 10,000 rads. The work of Uzorin and Demina (1965) reveals that the dry matter accumulation gets affected in tomato seedlings even under the influence of low doses of gamma-rays. Saric et al. (1961) have, however, found that in growing wheat seedlings the dry matter content increases in doses above 10,000 R due to the decreased rate of respiration. The result obtained in the present study further indicates that the loss in fresh weight happens to be higher than the dry weight, particularly under high dosage treatments, leading to the fall in their ratio. Nell and Silveira (1976) have also

observed the fresh weight of Phaseolus vulgaris to be more radiosensitive than dry weight.

In the present study, the delay in initiation of flowering in higher doses like 125 and 150 krads of M_1 generation has been due to the delay in the appearance of floral *branches which usually appear after 60 days of vegetative* growth in control and in lower doses but has been found to appear by two to three weeks later in higher dosages. Delayed and reduced flowering as an effect of ionizing radiations have also been reported by Johnson (1936b). Gunckel (1965) has found that with increasing doses of chronic gamma-rays, flowering is generally retarded. Bari (1971) has observed delayed flowering in Linum with increasing radiation exposure and at 100 R/day flowering has been observed to initiate about a month later. Flowering has been found to initiate simultaneously both in control and irradiated plants of Solanum khasianum (Chauhan, 1978). However, on the contrary, there are also few reports of stimulation of flowering as an effect of irradiation. Stimulated flowering has been reported in Nicotiana rustica by Gunckel and Sparrow (1954), in Impatiens sultanii by Gunckel (1957) and in Tradescantia paludosa by Gunckel et al. (1953a). Johnson (1948) has also reported early blooming in a group of irradiated Kalanchoe plants,

while Haskin and Moore (1935) observed premature flowering in Citrus plants grown from X-rayed seeds.

The number of capsules per plant, number of seeds per capsule and number of seeds per plant have been found to show a decreasing trend with increasing doses of gamma-rays in the present study. The marked reduction in yield per plant in higher dosages like 125 and 150 krads has been due to both reduction in number of capsules per plant and reduction in number of seeds per capsule. However, the yield picture in M_2 generation has proved to be different from what has been obtained in the first generation. The 25 krad treatment of M_2 generation has shown a slight increase in the number of seeds per plant in comparison to control and the increase has been mainly due to the increase in number of fruits per plant rather than the increase in number of seeds per capsule which has been almost equal to that of control. The recovery in terms of number of fruit per plant and number of seeds per capsule has been found to be considerable in high dosages like 100, 125 and 150 krads. Similar variabilities in yield contributing characters have also been found by a number of workers in the plants studied by them (De Nettancourt and Contant, 1966; Bari, 1971). Chauhan (1978) has observed a

decrease in yield, number of berries and weight of berry in gamma-irradiated Solanum khasianum. Seetharam (1976) has also reported a reduction of yield in linseed due to gamma-irradiation. Subhash et al. (1977) have observed 25 percent decrease in yield per plant as an effect of X-irradiation in Capsicum annuum.

A favourable effect of ionizing radiations on the productivity of plants is not uncommon in literature (Borojevic, 1965, 1966; Davies, 1960, 1970; Ismail et al., 1976). Breslavets et al. (1960) have reported an increase in yield in radish and carrots by presowing irradiation of seeds with X- and gamma-rays. Saric et al. (1961) have reported that definite doses of radiation act as a stimulant on growth, development and yield of plants.

Ionizing radiations are known to affect the complex metabolic processes in plants (Gunckel and Sparrow, 1961). The synthesis of higher fatty acids is one such complex process in which some chain-elongating enzymic systems present in the plant tissues are involved (Harlan and Wakil, 1963). Since, the enzymic systems are highly sensitive to ionizing radiations, variability in the fatty acids make up may be induced with the help of suitable ionizing radiations.

A lower percentage of oil in comparison to control has been obtained in the seeds of treated progenies of M_1 generation and this might have been due to gamma-ray - induced reduction in the cellular esterification of fatty acids. However, the treated seeds of M_2 progenies have shown a considerable recovery in their oil content. A slight increase in the yield of the oil has also been noticed in 150 and 25 krads of M_2 generation. Nath and Singh (1981) have also reported a similar increase in oil percentage in Sesamum indicum L. at 10,000 rads of gamma radiations. Labana et al., (1976) have advantageously used gamma-rays to evolve strains of Brassica species with higher oil content and better nutritive value. Bari (1971) have reported occurrence of high yielding yellow seeded plant of Linum in the M_2 generation of the 600 R/day in chronically irradiated material. The yellow seed colour in Linum is known to be positively associated with high oil content of superior quality (Culbertson and Kommedahl, 1956) and is attributed to the homozygous recessiveness of one or more genes (Barnes et al., 1960). Since the oil content has been found to be recovered in M_2 generation, the decline in yield during M_1 generation might not have been due to change at genic level.

It has also been found during present investigation that gamma-rays changed the relative composition of saturated and unsaturated fatty acids in the treated progenies of M_1 and M_2 generations and have slightly increased the degree of unsaturated component of the oil. It seems that the metabolic process responsible for the dehydrogenation of fatty acids, is stimulated by the gamma-rays. The formation of a saturated bond from unsaturated one is a feasible process which releases energy. On the other hand, the formation of an unsaturated bond from saturated bond is not a feasible process and requires energy. Therefore, the dehydrogenation of saturated fatty acid to an unsaturated one requires energy which might be provided by gamma-rays.

The increased degree of unsaturation, as obtained in the present study, has also been reported by Nath (1981) in an other variety of flax.

Variations :

During the present study the treated seedlings of M_1 generation have been found to show a number of morphological and anatomical variations. Induction of dichotomy (Plate V-C, Plate VI-A), fasciation (Plate IV-E, Plate V-E) and conversion of shoot-apex into leaf-like (Plate IV-A) or needle-like (Plate VI-B) structures as observed in the present study has also been observed by earlier workers in certain cases following exposure to X-, gamma- and thermal- neutron-irradiations (Johnson, 1933, 1948; Irving, 1940; Gunckel et al., 1953a; Gunckel and Sparrow, 1954; Sparrow and Gunckel, 1956; D'Amato, 1957; Carter, 1965; Gunckel, 1965). Flattening of the shoot-apex due to retarded meristematic activity has also been reported by Chauhan (1969) and Rai (1971). Johnson has described the reduction of leaf-blade, twisting of leaf-lets, and fusion of leaf parts as common in irradiated tomato plants (Johnson, 1931) and in Helianthus seedlings (Johnson, 1926). Similar leaf abnormalities (Plate V-D) have also been found to occur in Linum usitatissimum L. var. neslum in an increasing number with increasing doses of gamma-rays.

Fasciation and condensation of the floral stalks (Plate VI-C) as observed in the present study has also been

reported in sun-flower (Johnson, 1926), flax (D'Amato, 1957) and snapdragons (Gunckel and Sparrow, 1954). The inflorescences of Tradescantia paludosa, receiving 20-24 R per day for 8 weeks have been found to proliferate into a globose head by the formation of leaf like - structures and modified flowers (Gunckel et al., 1953b). Reduction in the size of the flowers (Plate I-C, D) and variation in number and colour of the petals as observed in the present study have also been reported in a number of plants (Moore and Haskins, 1935; Johnson, 1939; Sparrow and Pond, 1956; Sagawa and Mehlquist, 1957).

The pollen-fertility of the treated plants of M_1 generation has been found to be inversely proportional to the doses of gamma-rays employed in the treatment. However, a quick recovery of the damage has been shown by the treated plants of M_2 generation. A similar observation has also been made by earlier workers in different plants (Bari, 1971; Chopra, 1972; Nath, 1974; Abidi et al., 1978; Gangawar, 1980).

From the results obtained in the present study it can be inferred that the fall in the pollen-fertility in the irradiated plants of M_1 generation and their subsequent recovery in the second generation may in all probability be

due to the altered physiology of the pollen mother cells rather than to the genetic change caused by the irradiation treatments.

Gamma-rays have been found to cause serious damage in the plants of M_1 generation by reducing the length and width of tracheary elements. The diameter of vessels has also been found to show a decreasing trend with the increasing intensity of gamma-rays. Compared to M_1 generation, the M_2 generation has shown the damage to a lesser extent. The reduction in length of vessels and fibres has been reduced to 21 per cent from that of 37 per cent in case of vessels and to 25 per cent from that of 36 per cent in case of fibres under 150 krad treatment (Table 32). The extent of recovery, therefore, shows an increasing trend with the increasing intensity of gamma-rays. The width of vessels, on the other hand, has shown an increase under all treatments irrespective of the dosage and it happens to be higher than that of control. This increase in width of vessels in M_2 plants appears to have been developed to meet the water requirement of the plants when the length of the elements is still under the stress of gamma-rays. D'Amato (1957), while studying the effect of gamma-rays on another variety of flax, has come across that in the

treated plants there has been a thinning effect on secondary xylem as a result of gamma irradiation. In a recent report Ghouse et al. (1978) have noted that the xylem elements suffer a set-back in their dimension under the influence of gamma-rays in var. T397 of Linum usitatissimum, while Abidi et al. (1978) have reported that the gamma-rays induce the ground cells of cortex and pith to proliferate and grow in number in a direct proportion to the intensity of irradiation.

SUMMARY

SUMMARY

The effect of different acute doses of gamma-rays on *Linum usitatissimum* L. var. neelum has been studied in relation to morphological, anatomical and various growth responses of the crop under field conditions. The results obtained in the present study are summarised below:

1. The gamma-ray treatment does not appear to affect seed germination except at higher dose levels of 125 and 150 krads in which the process is getting delayed and hampered. The damaging effect of gamma-rays has not been observed in M_2 generation.

2. The survival fitness of the treated plants of M_1 generation has been found to be highly affected in a direct proportion to the level of dosage. The treated plants of M_2 generation have, however, been found to recover almost to its full extent.

3. The gamma-ray treatments have been observed to affect the different growth characteristics of the crop in a linear proportion to the dosage level.

4. The length of hypocotyl region of the seedlings has been found to undergo reduction under gamma-ray treatments. The M_2 progenies have been found to recover from this loss and they are stimulated to some extent by the low level doses.

5. The cotyledonary expansion as well as the dry matter content does not appear to undergo any marked alteration due to gamma-irradiation in M_1 as well as M_2 generations, although the fresh weight/dry weight ratio goes slightly higher in the first generation indicating the water holding capacity of the cotyledons of the treated progenies.

6. A general suppression in the root growth has been caused by gamma-ray treatments. The high doses above 75 krad have been found to retard root growth to a considerable extent. At no stage any stimulatory effect on roots has been noted in the M_1 generation. A general recovery from the bad effect of irradiation has been found to occur in the M_2 generation.

7. The height of the plant is highly affected by the gamma-ray treatment, the retardation in the rate of growth of the shoot-axis is being high at higher level of doses. The light doses, at the same time, have been found to stimulate the shoot growth. In M_2 generation the stimulatory effect of low doses has been found to persist while under high doses, the progenies recover to a considerable extent.

8. The gamma-ray treatments have been found to stimulate branching habit of the plant under low levels of irradiation while the same has been found to get affected under

high levels of irradiation. No such effect of the treatments has been noticed in the M_2 generation.

9. The number of leaves/plant has been found to be influenced by the gamma-ray treatments. While a low dosage like 25 krad has been found to bring about a slight increase in the number of leaves per plant, the other doses have brought down the leaf number, and the loss being directly proportional to the intensity of dosage. The gamma-ray effect has been found not to lost in the second generation.

10. The upper-ground, under-ground and the total biomass of the treated progenies have been found to be affected materially by gamma-irradiation treatments in a direct proportion to the dose level. The treated plants of M_2 generation appear to undergo considerable recovery of the losses incurred in the first generation.

11. The gamma-ray treatments given to the seeds have been found to reduce the yield of the progenies by affecting the number of capsules/plant and the number of seeds/capsule in a direct proportion to the dose level. In M_2 generation, an increase in yield in terms of number of fruit per plant has been observed under low doses like 25 and 50 krads. No change in yield in 75 krad and a reduced one in higher dose have been found in the second generation, the reduction being considerably low

in this generation in comparison to that of first.

12. The yield in terms of oil content has been found to be affected by the gamma-ray treatment but not in a direct relation to the dose level. In M_2 generation, the loss in oil content of the seeds appear to undergo recovery and at the same time an enhancement at the lowest as well as at the highest levels of irradiation treatments indicating the effect being inconsistent and irregular.

13. The relative amounts of various fatty acid components have been found to undergo a change in the ratio of the saturated and unsaturated components under the influence of irradiation treatments. The disturbance in the above ratio has also been observed to exist in the second generation.

a - Linolenic acid content of the oil has been found to increase in the treated plants except under 150 krad treatment of M_1 generation and there has been an over all increase in this fatty acid content of the oil in second generation under all levels of irradiation.

b - Linoleic acid content of the oil has been found to increase in all the treated progenies of M_1 generation excepting the 150 krad treatment but in the second generation an increase in this fatty acid

content has met with only upto 100 krad treatment, while under the other two treatments (125 and 150 krads) its amount has been found to fall below the line of control.

c - Oleic acid content has been found to decrease in all the treated progenies except that of 150 krad treatment in which its amount raises above the level of control. In M_2 generation, however, there is a consistent decrease of the Oleic acid fraction irrespective of the dose level.

d - Stearic acid component of the oil increases in the progenies of 25 and 50 krad treatments but not in other treatments of M_1 generation. In the second generation, an increase in Stearic acid component has been found under all treatments except that of 100 and 150 krads.

e - There is a general decreasing trend of the Palmatic acid content under all treatments excepting that of 75 krad in which a reverse trend has been noted. In M_2 generation, this fatty acid component has been found to decrease under all treatments with out any exception.

14. A number of morphological and anatomical variations have been found to occur in the gamma-ray treated progenies.

The frequency of variance has been found to increase with the increasing dosage of gamma-irradiation. The following variations have been come across in the different treated progenies.

a - Stem bifurcation, twisting, fasciation, variegation and conversion of shoot-apex into leaf-like structure.

b - Reduction, fusion, deformation, variegation and curling of leaves.

c - Flattening and condensation of floral axis and reduction, discolouration and fusion of flowers.

d - Reduction in the length of vessels and fibres.

No variation of the above kind has been noted in the M_2 generation except the dimensional one of the secondary xylem components and this too has been noted to undergo a considerable amount of recovery in M_2 generation.

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* Not seen in original.

PLATE I

A-B : Show the experimental plants under potted and field conditions respectively.

C : Shows an abnormal plant of 100 krad treatment having normal (arrow) and reduced (black arrow) flowers in different branches of the same plant.

D : Same as C but on two different plants of 100 krad treatment.

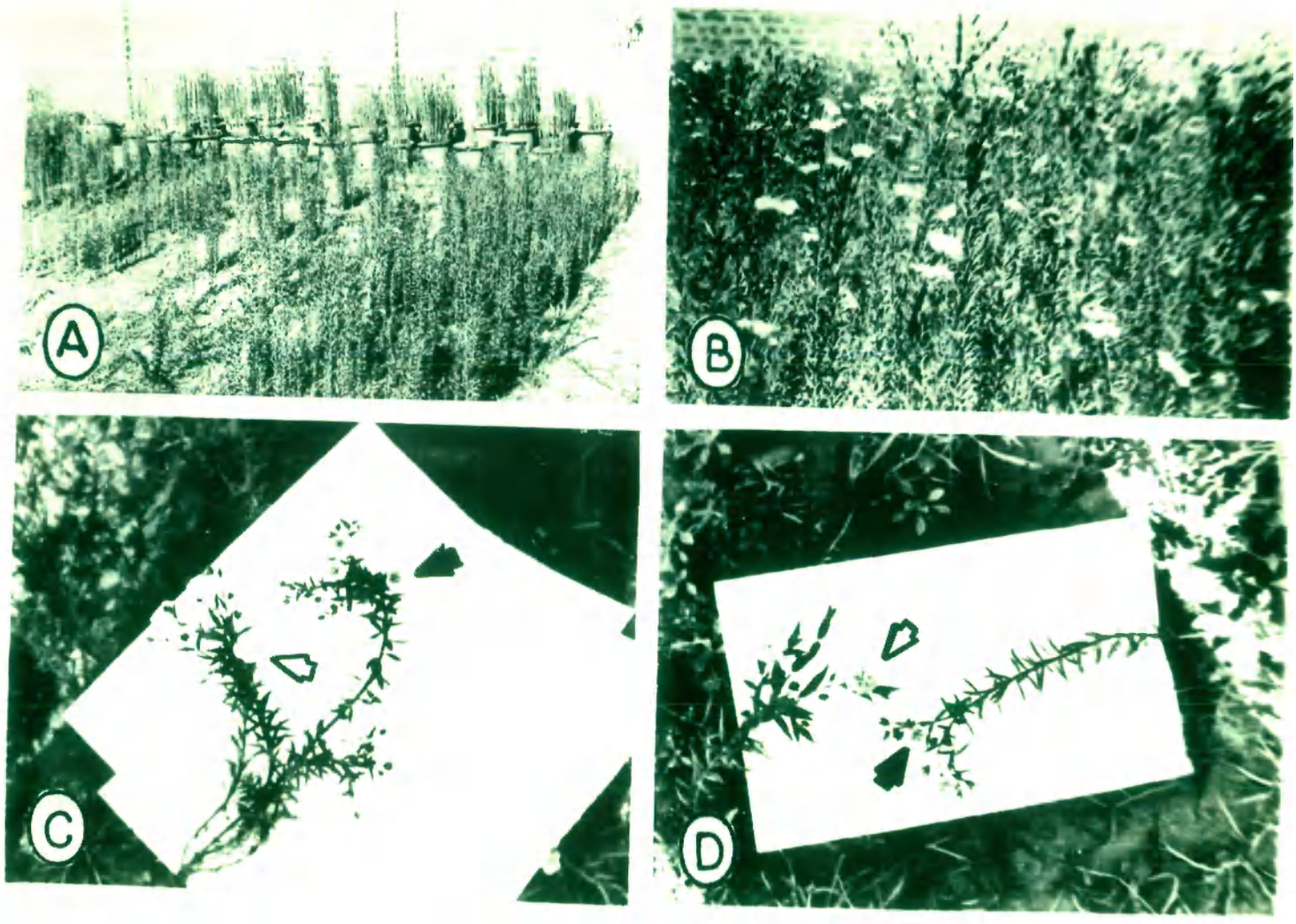

PLATE I

PLATE II

A-G : Show the growth performance of control and treated seedlings of *Linum usitatissimum* L. var. neelum in pot condition.

A - control, B - 25 krad, C - 50 krad,
D - 75 krad, E - 100 krad, F - 125 krad,
G - 150 krad.

PLATE II

PLATE III

A-G : Shows the growth performance of control and treated seedlings of *Linum usitatissimum* L. var. neelum in field condition.

A - control, B - 25 krad, C - 50 krad,
D - 75 krad, E - 100 krad, F - 125 krad,
G - 150 krad.

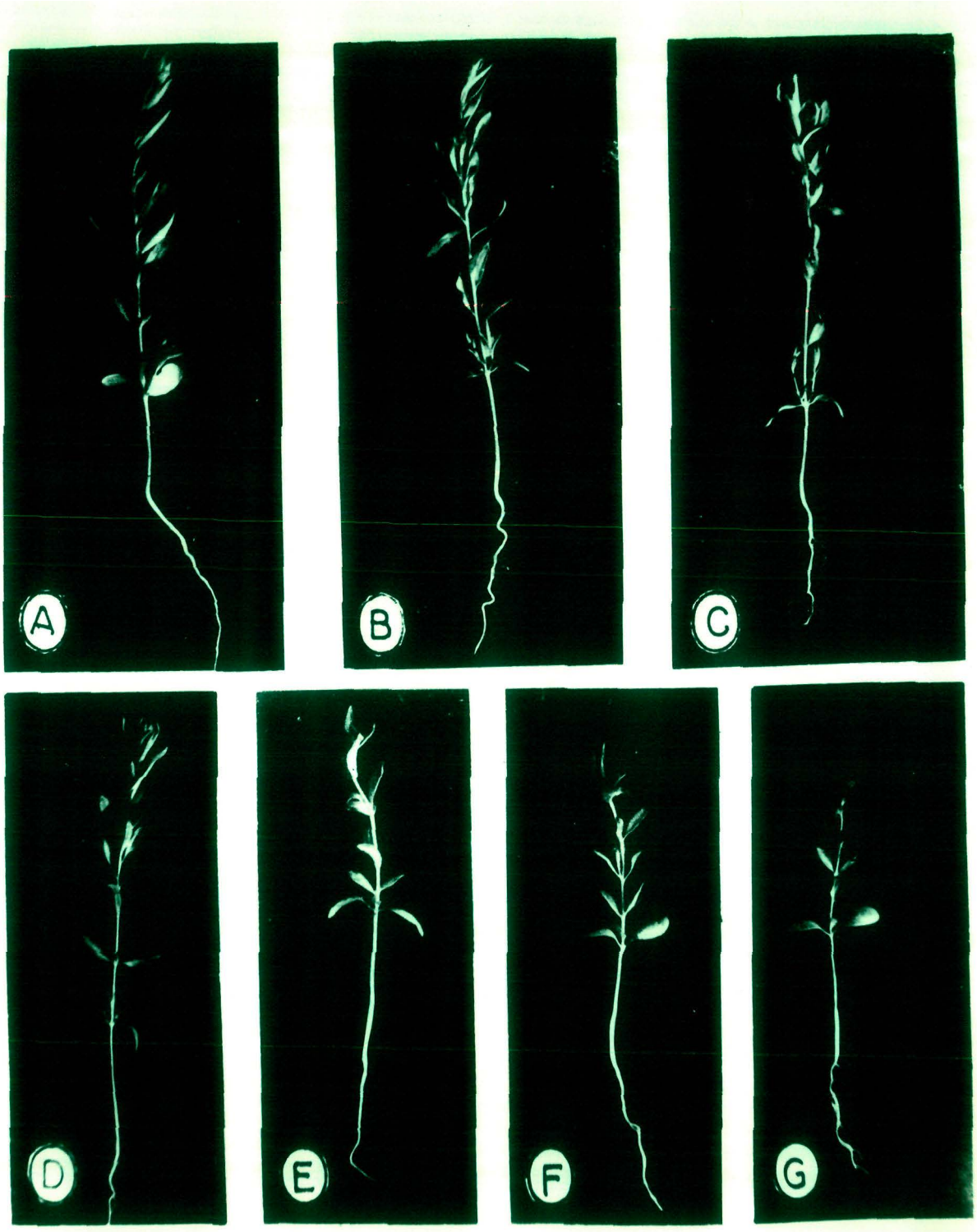

PLATE III

PLATE IV

A-E : Show the morphological variations in the gamma-ray treated progeny of *Linum usitatissimum* L. var. neelum in M_1 generation.

A : Shows forking of shoot-axis (black arrow), conversion of shoot-apex into a leathery leaf (arrow) and production of reduced leaves in one of the sister branches under 150 krad treatment.

B-C : Show the curved shoot-apex in the affected individuals under 150 krad treatment.

D : Shows the development of narrow needle-like leaves at the distal region of an individual affected by 125 krad treatment.

E : An affected individual under 150 krad treatment showing flattened stem and condensed apical region.

PLATE IV

PLATE V

A : Shows a plant under 100 krad treatment having normal lateral sheets and the main sheet showing arrested growth (arrow). Note the variegated distal end of the main sheet.

B : An individual showing a variegated lateral branch (arrow) under 150 krad treatment.

C : An affected plant under 100 krad treatment showing bifurcation of the sheet-axis and unequal rate of development of the branches resulting in lateral displacement of the slow growing branch (arrow).

D : Shows the morphological variations in leaves due to gamma-ray treatments.

E : A fasciated sheet-axis with condensed apical region having crowded abnormal leaves (reduced and narrow) under 75 krad treatment.

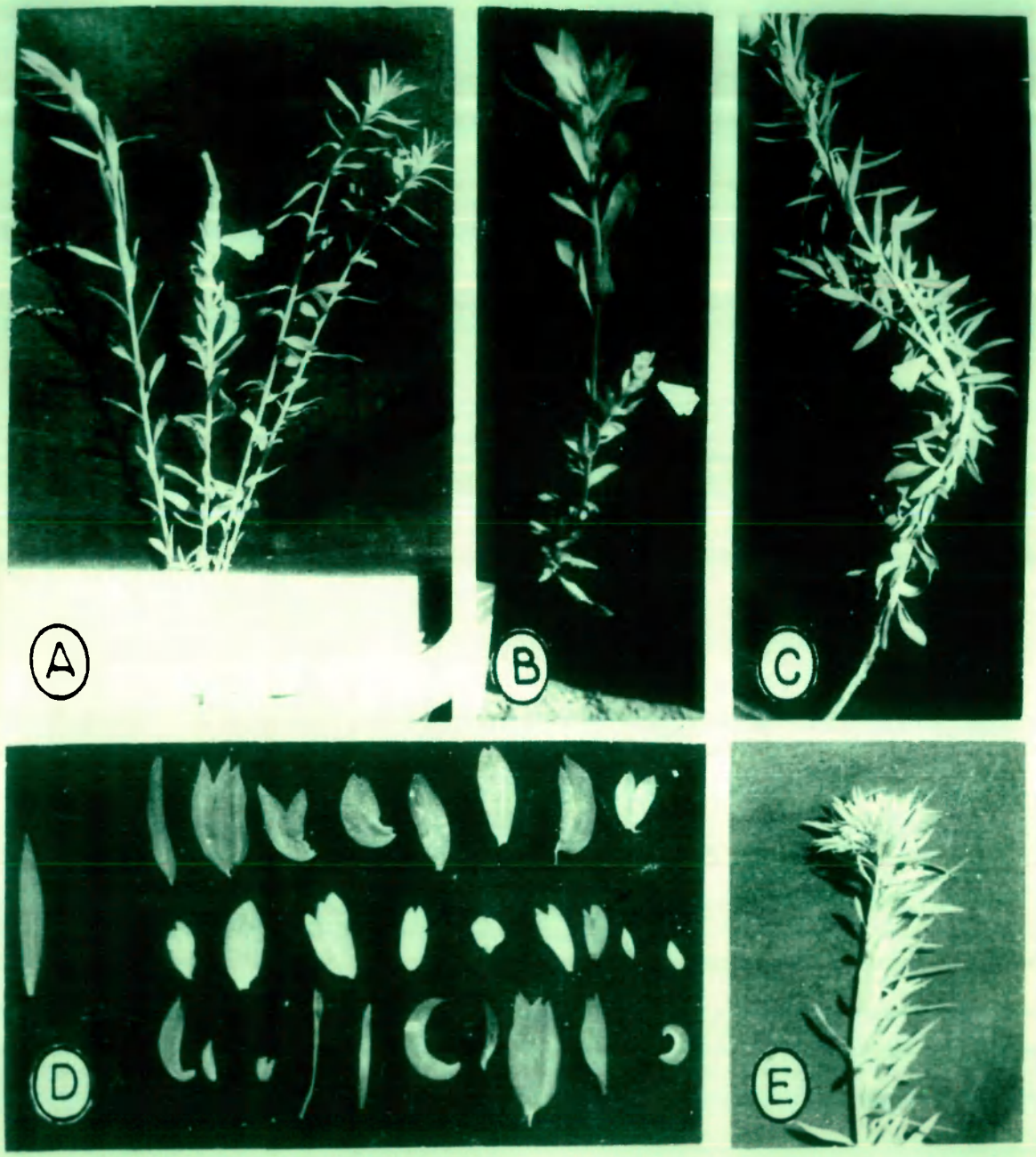

PLATE V

PLATE VI

A : A bifurcated sheet showing normal leaf development under 75 krad treatment.

B : Shows a sheet apex converted into a needle - like cylindrical leafy structure (arrow).

C : A fasciated sheet showing a condensed floral-axis with flowers crowded into a head - like structure under 75 krad treatment.

D : Shows the floral head of C developed into a composite fruit. Note that normal fruits also developed in a normal branch of the same individual.

PLATE VI